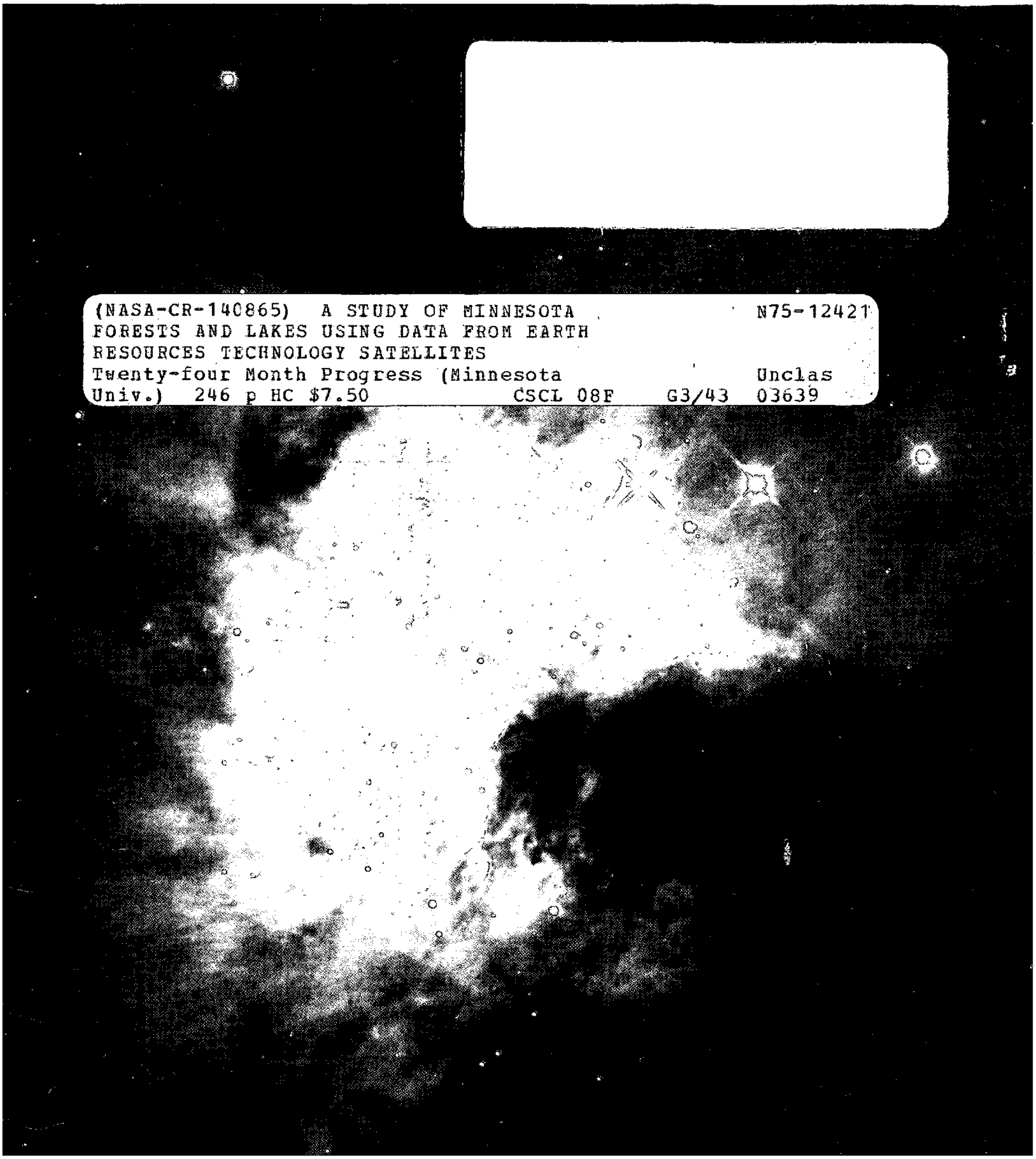
UNIVERSITY OF MINNESOTA
SPACE SCIENCE CENTER



(NASA-CR-140865) A STUDY OF MINNESOTA FORESTS AND LAKES USING DATA FROM EARTH RESOURCES TECHNOLOGY SATELLITES Twenty-four Month Progress (Minnesota Univ.) 246 p HC $7.50 CSCL 08F

N75-12421
Unclas
G3/43 03639

SPACE SCIENCE CENTER

University of Minnesota

Minneapolis, Minnesota 55455

A STUDY OF MINNESOTA FORESTS AND LAKES USING DATA FROM EARTH RESOURCES TECHNOLOGY SATELLITES

TWENTY-FOUR MONTH PROGRESS REPORT

June 30, 1974

Supported by:

NASA GRANT NGL 24-005-263

Submitted to:

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Washington, D.C. 20546

TABLE OF CONTENTS

SPACE SCIENCE CENTER

TWENTY-FOUR MONTH PROGRESS REPORT

JULY 1974

INTRODUCTION

This report, at the end of the second year of the NASA sponsored Remote Sensing Program at the University of Minnesota, is organized into separate individual reports by the individual researchers. There are, however, a few items of more general, program wide, nature that can be emphasized in this introduction. In the second year we have been attempting to concentrate even more strongly on practical results. We note here the highlights of practical benefits achieved in the second year, indicate a few observations on achieving practical results in future years and close with a brief review of how the program emphasis has shifted during the first two years of operation.

The Lake Superior studies program conducted by Professor Sydor and his associates introduced a new group to remote sensing. They have made remarkable progress and now occupy a central position in combining remote sensing observations with direct lake soundings and in providing municipal, state, federal, and industrial users with necessary practical information. The forest studies of Professors Meyer and French have progressed to the point of showing state and local agencies direct financial benefits of remote sensing in large scale inventory of forest resources and rapid identification of diseased trees. Professor Rust has demonstrated the utility of saline soil identification by remote sensing but there is some problem with the users (county agencies and farmers) in how such studies can be financed. Lakes and watersheds are under study by Professors Mace, Skaggs and Brown with considerable success in making water resource maps and water quality indications available to people who need this information. The flood prediction models of Professor Bowers are benefitted by the wide scale snow cover information available from ERTS images. A problem remains, however, in getting the images quick enough to be useful in current year predictions.

Educational benefits from the program take two forms. Many of the faculty investigators benefit through learning how to use the remote sensing data directly and in talking to others already in remote sensing. Graduate students and undergraduate students are trained directly in remote sensing while working on the projects supported. Several of them are mentioned by name in the individual reports. Remote sensing courses continue to be offered through the Institute of Agriculture Remote Sensing Laboratory and the Department of Geography, a new course in remote sensing has been introduced on the Duluth Campus and several short seminars have been organized to provide remote sensing information to the public.

Several problems remain in the program. One lies in the reporting of project results. Often the operational details of obtaining the pertinent information from the remote sensing images is omitted from reports. A good example of a more complete account of how the information is obtained is contained in the M.S. thesis of Steven J. Prestin, page 99 of this report. There also remains some confusion about identifying practical results. We believe there is a spectrum of possible results from these remote sensing projects progressing from very little practical content to some ideal situation. At the least practical end of this spectrum is the traditional method of academic research, publication of results in a scientific journal. The results presumably are of high scientific qualtiy, referred by the investigator's peers, but are usually written in a style that can be best understood by scientific colleagues. A potential practical user must seek out this information and translate it into terms he can use. Another step in the spectrum includes identification by the investigators of how the results might be useful in a practical sense. Here the investigator may identify agencies that might use the information, how they could use it and even estimate what financial benefits might result. The practical potential of the research is certainly enhanced simply because the investigator has considered the practical side.

Even more practical utility may be achieved if the investigator contacts users directly, explaining the usefulness of the information to them and helping them adapt the results to their own problems.

One can conceive an ideal situation when the users and the investigators work together closely in planning the research. The conduct of the research is then designed to solve practical problems from the beginning and the practical user is an important part of the research process.

The remote sensing investigators at the University of Minnesota are spread along the spectrum we have briefly described. Some projects are inherently more suited to practical results than others. Much supporting research of a purely scientific nature must be done to validate the practical results of interest to a user. The user may want only a small part of the final stages of the investigation. It is the responsibility of the investigator to see that the essential scientific basis of the practical result has been carefully and completely done. Our intent in this program is that all of our projects be working toward practical results and that some of the projects achieve practical results each year. Finally we believe that the limited financial resources of the program demand that it support mainly seed projects. New researchers are introduced to remote sensing, work towards practical results, succeed in attracting other financial support for the operational phase of the research and are replaced by additional new projects.

In the first year of this program, we started eight faculty members in

Remote Sensing projects. Six of the faculty had previous experience in Remote Sensing, two had none. At the end of the first year, we were a little disappointed with the program. Part of the problem was our lack of experience with directing this type of program with strong emphasis on practical results and interaction with user agencies. During the second year, we attempted to exert more guidance on the program by holding several meetings with investigators where we discussed practical research goals and progress toward those goals. We also reserved a portion of the annual funds for new applications during the second year or for increased support for promising projects. Second year support was decreased for five of the more experienced faculty and one of the new researchers in Remote Sensing. We increased second year support for two of the experienced and one of the new researchers, and started two additional faculty members without previous experience in Remote Sensing.

Now we are somewhat more encouraged by the progress toward practical results. One of the faculty introduced to Remote Sensing two years ago has made impressive progress, becoming in great demand for advice in the technical application of Remote Sensing. He has also managed to attract support from the State and from other Federal agencies for his Remote Sensing work. Another new researcher, from two years ago, has found less interest and considerable difficulty in applying Remote Sensing and has left the program. One of the new second year researchers has withdrawn, while the other is making encouraging progress.

Overall, the program has been beneficial to the faculty involved and to Minnesota. Two people have been introduced to Remote Sensing and have made substantial practical use of it. Some of the Remote Sensing veterans have accepted the challenge for practical results and have substantially changed their traditional research objectives to include more emphasis on practical benefits. Some of the researchers have been unable to make much progress to practical results in their research.

In the future we plan to continue investigator meetings to identify and monitor practical goals. We are also trying to introduce still other new researchers to Remote Sensing. This will require gradually reducing support to researchers whose interest in practical applications of Remote Sensing declines as well as those who became experienced and are able to find increasing support from other agencies.

The following chapters include a review of the activities during the last year.

FOREST DISEASE DETECTION AND CONTROL

Investigator: Dr. D. W. French
Department of Plant Pathology
University of Minnesota, St. Paul

ABSTRACT

Present techniques for detection of Dutch elm disease by means of aerial photography are not satisfactory because of cost in relation to success (42%) of detection. It is feasible to use aerial photography for detecting oak wilt as it costs no more than ground survey, requires less time and provides an accurate map of the infection centers. Detection of tree diseases from a helicopter is of value in checking on other methods of survey.

INTRODUCTION

In our previous report (IARSL Research Report 73-1) dated July, 1973, we summarized our findings in detecting dwarf mistletoe in black spruce stands, hypoxylon canker in aspen stands, and Armillaria root rot in red pine plantations. Studies were continued with these three diseases, but in 1973 the emphasis was shifted to the detection of oak wilt and Dutch elm disease in metropolitan areas. The reason for being concerned about these two diseases was the sudden interest in many communities faced with the problem of detecting these diseases quickly and efficiently.

Thus, in this report we have summarized our findings in detecting Dutch elm disease in North St. Paul (A), and oak wilt in North Oaks (B). These two communities were selected because we had excellent ground truth enabling us to compare costs and efficiencies of the various techniques for surveying diseased trees.

STUDY DESIGN, DATA COLLECTION

A. North St. Paul is a small community of approximately 3.1 square miles with a reasonably high incidence of elms with Dutch elm disease. In previous studies we had too few diseased elms or the diseased trees were removed before we could complete our studies. In North St. Paul almost every diseased tree was left until we had completed our observations. Three methods of survey were compared: aerial photography, direct aerial detection with helicopter, and on-ground checking.

The aerial photography was completed on August 13, 1973, by Mark Hurd Aerial Survey, using a 9x9-inch format, a scale of 1:9,600, and Ektacolor film. Stereo coverage was obtained and interpretation was accomplished with the color prints using an acetate overlay for marking trees. The direct aerial observation with a helicopter was done from 9:00-10:00 a.m. August 17, 1973, on a day when weather conditions were not optimum, but reasonably good for this purpose. Two observers were used, not including pilot, with one person recording and the second person attempting to keep track of locations. The helicopter flew at 300-400 ft and a speed of 25-30 mph. The diseased elms were in about the same condition for both aerial photography and the helicopter survey.

The ground surveys by the City of North St. Paul were underway throughout the months of July and August. A complete survey on the ground was completed by us within a few days following the aerial surveys. There again the condition of the trees was comparable for all three surveys, excluding what was done by the City of North St. Paul. The ground survey by University personnel was used as the basis for evaluating all of the surveys.

B. North Oaks has about 1800 wooded acres which are mainly a mixture of various species of oaks. Photography was obtained in 1971, 1972, and 1973. The 1973 material has not been evaluated as yet. In 1971, Ektachrome MS film with a Wratten #2A filter (EMS2A), Ektachrome infrared 8443 film with a Wratten #15 filter (EIR15) and Ektachrome infrared 8443 film with a Wratten #21 filter (EIR21) were used. Four scales, 1:6,000, 1:12,000, 1:24,000 and 1:31,680 were used. In 1972 only, Ektachrome infrared film with a Wratten #21 filter and a scale of 1:24,000 was used. In both years 70mm cameras were used. Dates of photography ranged from August 4-11 and from 0930 to 1035. All of the combinations used are summarized in Table 1.

Table 1. Aerial Photography and Flight Condition Variables

Film	Filter (Wratten Number)	Shutter Speed, f no.	Focal Length	Scale (altitude)	Date	Time	Solar Alt.	Cloud Condition	Haze
Ekta MS	2A	(1/5000,4)	50mm	1:6,000 (950')	8/11/71	0930 CDT	47	Widely scattered cumulus	Med.
Ekta IR	15	(1/500,5.6)	50mm	"	"	"	47	"	"
Ekta IR	21	(1/500,4/5.6)	50mm	"	"	"	47	"	"
Ekta MS	2A	(1/500,4)	80mm	1:12,000 (3150')	8/4/71	0945 CDT	50	Very light cirrus	Med.
Ekta IR	15	(1/500,4)	80mm	"	"	"	50	"	"
Ekta IR	21	(1/500,4/5.6)	80mm	"	"	"	50	"	"
Ekta MS	2A	"	80mm	1:24,000 (6300')	"	0955 CDT	52	"	"
Ekta IR	15	"	80mm	"	"	"	52	"	"
Ekta IR	21	"	80mm	"	"	"	52	"	"
Ekta MS	2A	"	80mm	1:31,680 (8310')	"	1005 CDT	52	"	"
Ekta IR	15	"	80mm	"	"	"	52	"	"
Ekta IR	21	"	80mm	"	"	"	52	"	"
Ekta IR	21	(1/500,4/5.6)	80mm	1:24,000 (6300')	8/4/72	1035 CDT	54	Very light cumulus	Light

The ground data were obtained by a University survey crew without prior knowledge of what was detected on the aerial photography. The two surveys were then compared at a later date.

DATA ANALYSIS

A. A total of 109 elms with Dutch elm disease were located in North St. Paul. Considering the thorough coverage of the community, we expect this is a reasonably accurate estimate.

Direct aerial observation from the helicopter resulted in the detection of 74 of the total 109 diseased trees, or 67.9%. Of the 74 trees located, 18 (24.3%) were incorrectly located on the map. As a general rule these mislocated trees were one block off and were not difficult to find on the ground. An additional 8 trees (9.8%) were marked as cases of Dutch elm disease but actually were not elms. Three elms (3.5%) were marked as cases of Dutch elm disease but were not infected. One tree which had been missed by ground survey crews was detected from the helicopter. This technique required less than one hour for the 3.1 square miles, and the cost was $105.00 for the helicopter and $10.00 for the time of the observers for a total of $115.00

Interpretation of aerial photography resulted in the location of 49 (42.2%) of the 109 diseased elms. A total of 381 trees were marked as possible cases of Dutch elm disease, of which 49 or 12.9% were positive and 332 or 87.1% were negative. The relatively poor results with aerial photography are due in part to film selection. Undoubtedly, Ektachrome infrared film would have provided more accurate data. The infrared film was not available, and thus Ektacolor was selected as the next best choice. The cost of the photography was $625, and in addition to providing the data on Dutch elm disease, also provided excellent maps of the community, which could be used for other purposes. The total cost of this technique would need to include an item for the photo interpreter.

Of the 109 diseased elms, 80 were located on the ground by the North St. Paul personnel. The survey by University personnel resulted in locating all but two of the total number of diseased trees. One of these two trees was located by the City and the second by observation from the helicopter. Both of these trees were detected on the aerial photos. The ground survey required approximately 2 days by two people, or a total of 32 hours. Assuming a salary of $5.00 per hour, the ground survey cost a minimum of $180 with labor and vehicle expenses included.

Thus the aerial photography was the most expensive technique and the least efficient at 42% detection. Direct aerial observation cost less and was more effective in detecting Dutch elm Disease (67.9%). Ground survey was the least expensive, but approximately the same as that for the helicopter system. Ground survey resulted in the greatest degree of accuracy, 80% by the City. The City costs of ground survey, because they extended over a longer period of time, were at least twice the costs of the University ground survey. Therefore, ground survey is probably intermediate in cost and is somewhat more efficient than direct observation from a helicopter. The diseased trees were accurately located on the aerial photos, but not always in the case of observation from the helicopter. Ground survey results in accurate location of trees, but does require some care in marking these trees on a map.

B. The results for both 1971 and 1972 are shown in Table 2. The 1971 interpretation indicated the following:

1. Accuracy of detection of disease centers on aerial photos increased with larger scales.

2. Commission errors increased with larger scales.

3. The reasons for commission errors, including identification of dead trees, dead branches, other species, errors in interpretation, and those later discovered to have oak wilt the following year, increased with larger scales.

4. Total interpretation time, including actual interpretation and set-up and take-down time, increased with larger scales.

Table 2. Results of photo interpretation on the various film/filter/scale combinations.

Date	Scale	Film/Filter	Disease centers located on photo and on ground[1]		Omission errors		Commission errors		Reasons for Commission Errors: Detected dead tree	Detected dead branches	Detected other species	Detected in following year with oak wilt[3]	Error in interpretation (detected either undergrowth or shadows)	Interpretation efficiency	No. of frames interpreted	Total interpretation time (min.)	Order of interpretation
			No.	%	No.	%	No.	%[2]									
8/11/71	1:6,000	EMS2A	43	90	5	10	44	51	11	10	3	6	14	.88	12	66	12
		EIR15	37	77	11	23	42	53	10	13	2	4	13	.68	12	64	11
		EIR21	35	73	13	27	44	56	11	10	2	6.	15	.58	12	67	10
8/4/71	1:12,000	EMS2A	29	60	19	40	24	45	7	3	1	5	8	.73	5	50	9
		EIR15	35	73	13	27	22	39	8	2	2	5	5	1.16	5	50	9
		EIR21	35	73	13	27	26	43	10	4	1	5	6	.99	5	54	7
8/4/71	1:24,000	EMS2A	20	42	28	58	6	23	3	0	0	3	0	1.40	3	43	6
		EIR15	25	52	23	48	10	29	2	0	0	5	3	1.30	3	48	5
		EIR21	30	62	18	38	10	25	5	0	0	3	2	1.86	3	49	4
8/4/71	1:31,680	EMS2A	18	38	30	62	6	25	3	1	0	2	00	1.14	3	39	3
		EIR15	19	40	29	60	4	17	3	0	0	1	0	1.90	3	45	2
		EIR21	21	44	27	56	9	30	5	2	0	2	0	1.03	3	52	1
8/4/72	1:24,000	EIR21	33	100	0	0	21	0	17	1	0	N/A	3	1.57	3	45	13

[1] Total number of disease centers in 1971=48
Total number of disease centers in 1972=33.

[2] $\% \text{ Commission Error} = \frac{\text{No. commission errors}}{\text{No. disease centers located} + \text{No. of commission errors}} \times 100$

[3] These trees, although not determined to have oak wilt according to the 1971 ground survey, did have wilt in 1972.

5. Except for the largest scale, 1:6,000, accuracy of detection of oak wilt infection centers increased from the EMS2A to the EIR15 to the EIR21 film/filter combination. For the largest scale this order was reversed. For the 1:12,000 scale the EIR15 and EIR21 were equally as accurate.

6. Commission errors were least for the EIR15 film/filter combination for scales 1:6,000, 1:12,000, and 1:31,680. For the 1:24,000 scale, the EMS2A film/filter combination had the least number of commission errors.

7. Except for incorrectly identifying dead trees as oak wilt infection centers, no film/filter combination was significantly different in the reasons for commission errors. The EIR21 film/filter combination at the three smaller scales had a greater number of dead tree commission errors.

8. Interpretation time increased from film/filter combination EMS2A to EIR15 to EIR21 except for scale 1:12,000 in which EMS2A and EIR15 were equal, and scale 1:6,000 in which interpretation time for EIR15 was shorter than for EMS2A.

The 1972 interpretation indicated the following:

1. All disease centers were accurately located on the EIR21/1:24,000 film/filter/scale combination.

2. Commission errors were relatively high at 39%, with most of these in the "dead tree" category.

3. Interpretation time for this film/filter/scale combination bettered the average for the previous year's combination.

The costs for the aerial photo survey and the ground survey are in Table 3.

SUMMARY, PRACTICAL IMPLICATIONS

A. Dutch elm disease detection

Our studies continue to indicate that detection of Dutch elm disease with aerial photography is not a satisfactory system for detecting this disease and that further development of the technique

Table 3. Cost comparison between aerial photo interpretation and ground surveys for detecting oak wilt.

	Ground survey	Aerial photo survey
Aircraft and automobile transportation	30 miles/day for 2 days @ $.10/mi for vehicle = $6.00	30 miles/day for 1 day @ $.10/mi for auto = $3.00 ½ hour @ $50.00/hr for aircraft = $25.00
Film and processing	---	$21.00
Aerial photo interpretation	---	1 hour @ $7.00/hr = $ 7.00
Ground survey	27 manhours @ $3.21/hr = $86.67	4 manhours @ $3.21/hr = $12.84
Total cost	$92.67	$68.84

is necessary before such a system can be recommended to the public (Figure 1). Resolution of this problem is of considerable interest to many communities which are suddenly faced with the problem of surveying for this disease. Our studies and publication of the results should protect these communities from spending money on a system which will not provide useful information. In the current study in North St. Paul, we were able to detect only 42% of the diseased trees and had a magnitude of commission errors which would require a great deal of time to check on the ground. Although part of the expense of the photography could be justified on the basis of the value of the photos for other purposes, the cost is considerably above that needed for other types of surveys.

We did find that direct observation from a helicopter is probably of tremendous value in double checking a ground survey or the progress of a control program. The helicopter allows a reasonably priced system that can be used to quickly check to see if any trees have been missed in a sanitation program. We believe this is the real value of this system.

B. Oak wilt detection

It appears that with some further development that it is feasible to detect oak wilt by means of aerial photography (Figure 2). Many communities concerned about oak wilt could expedite their control programs with aerial photography. It is important that these communities receive the best possible advice on how best to apply this technique.

In 1971 the E2A/1:6,000 film/filter/scale was considered satisfactory for detection of infection centers, but even for this combination commission errors were considered excessive. With more experience, the interpreter could improve this system. An attempt was made to determine the optimum combination based on a maximum number of correct interpretations and a minimum number of commission errors. The formula, noted earlier, was devised to determine the efficiency of interpretation for the film/filter/scale combinations. That method indicated that the EIR21/1:24,000 combination would be the most efficient for a trained interpreter.

Figure 1. Floodplain and bluff forest along Elk River, Minnesota, with scattered trees infected with the Dutch elm disease. Even with high quality, large scale color infrared aerial photography such as this, success in detection of diseased trees was extremely poor.

Figure 2. Oak wilt occurence south of North Branch, Minnesota. Fungus apparently started in trees wounded by pipeline construction (located 1¼ inch from lower edge of photo). In 11 years 521 red oaks were killed. Color infrared of this quality at scales of 1/10,000 to 1/15,000 should usually be adequate for detection of this disease.

In 1972 all of the diseased centers were located on the EIR2I/1:24,000 combination. Commission errors were relatively high though at 39%. Dead trees accounted for most of these commission errors because the interpreter erred on the safe side in calling a suspect center diseased or not. This is not a serious problem, however, because it is well to know where incative infection centers are located in addition to those that are active.

The small scale 1:24,000 did prove difficult to work with because of: (1) the small detail; (b) the delineating and symbolizing on the acetate overlay; and (c) the necessity of enlarging the overlay to compare it with ground information. It was also a little more difficult locating a suspect tree on the ground using the small scale aerial photo as a guide.

EVALUATION OF WATER QUALITY BY REMOTE SENSING TECHNIQUES

Investigator: Dr. Arnett C. Mace, Jr.
Department of Forest Biology
University of Minnesota, St. Paul

ABSTRACT

A multispectral overflight at scales of 1:3,000 and 1:6,000 using 70mm and 35mm photography was made over Lake Minnetonka in late August, 1973, to evaluate water quality parameters, particularily primary productivity. Analysis of the relationships of 2402 Plus-X Aerographic/Wratten 25 film/filter combination negative film densities to phytoplankters, secchi disc depth and estimated chlorophyll concentrations indicated a significant correlation. Prediction equations were developed for these relationships. Correlations of other film/filter combinations with these water quality variables were not successful. Differentiation of some aquatic vegetations species by film density measurements was possible with all film/filter combinations.

INTRODUCTION

An increasing emphasis is being placed upon maintenance and improvement of water quality by federal, state and local governments as well as industry, private groups and citizens. However, a prerequisite for the maintenance or improvement of water quality is an assessment of the present status, estimate of trends, and identification of cultural activities which may contribute to processes governing water quality.

Assessment of the present status and future trends have generally been classified by some productivity function of the water system as being either eutrophic, mesotrophic or loigrotrophic. Many different parameters are either directly or indirectly related to the trophic status or productivity of the water body. However, primary productivity parameters and standing crop are most frequently used to estimate the trophic level. While numerous parameters can be used to define primary productivity; phytoplankton count, secchi disc depth, and chlorophyll content are commonly used.

Although techniques are presently available for assessment of these primary productivity indicators, they cannot provide the necessary areal or temporal monitoring required by present federal, state and local legislation. This study was designed to evaluate the potential of remote sensing technology to monitor status and trends in primary productivity of water systems of large areas on an economical basis.

STUDY DESIGN, DATA COLLECTION

The area studied was Lake Minnetonka which is located in east-central Minnesota. This lake has fifteen major bays and total acreage is 14,469 acres (Figure 1). It lies in an urban area with approximately 95 percent of its shoreline occupied by private homes, many with septic tanks. Six municipal sewage treatment plants discharge secondary effluent either into the lake or its tributaries. The contribution of the waste materials coupled with a high recreation demand makes this lake very productive.

The bays used in this study were Halsted, Priest, Cook, Spring Lake and Carmen (Figure 2). These bays were chosen to represent a range of productivity conditions and to utilize information obtained from other limnological studies (1).

The overflight was made on August 27, 1973 to obtain information during a period of high productivity. Film/filter combinations used during the overflight at scales of 1:3,000 and 1:6,000 are as follows:

35mm Aerochrome Infrared/Wratten 15
35mm Kodacolor-X/no filter
70mm Aerochrome Infrared/Wratten 15
70mm 2402 Plus-X Aerographic/Wratten 25
70mm 2402 Plus-X Aerographic/Wratten 58
70mm 2424 Infrared Aerographic/Wratten 89B

Table 1 provides a description of these films and Table 2 shows the filter specifications in percent transmittance. The 70mm film was shot in a quadricamera mount using four Hasselblad cameras while the 35mm film was shot using a Minolta motordrive camera on a side mount.

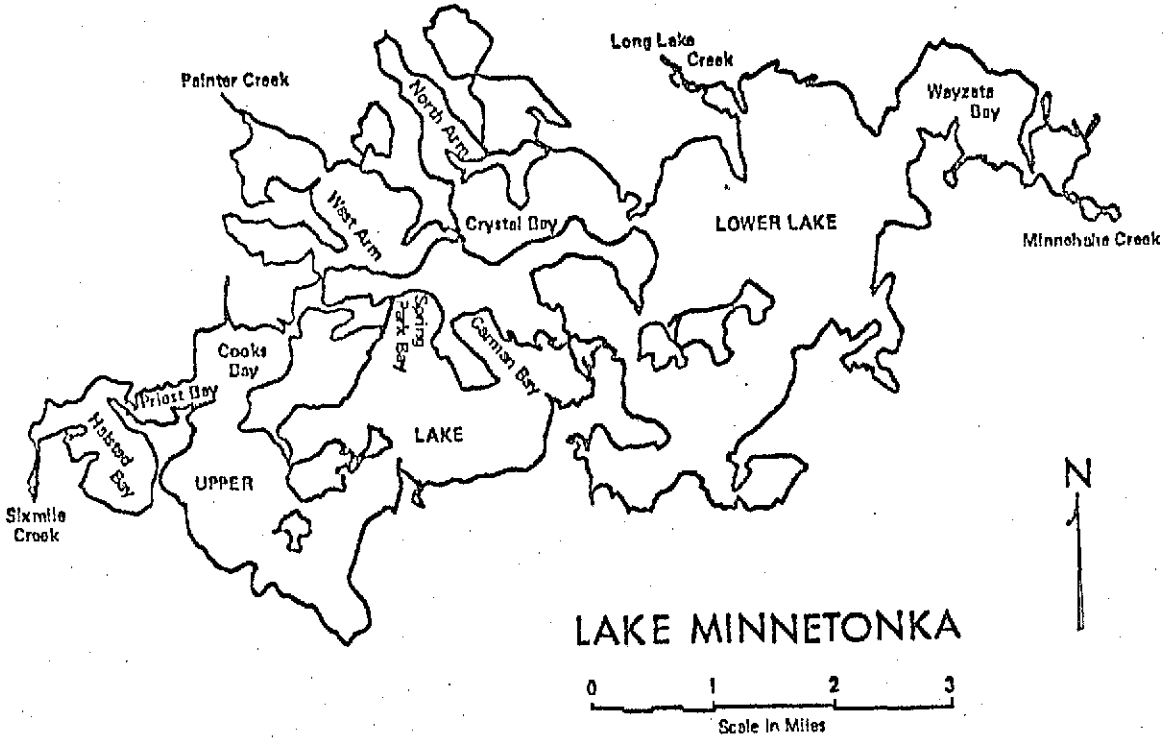


Figure 1. Location of bays sampled during overflight - Lake Minnetonka.

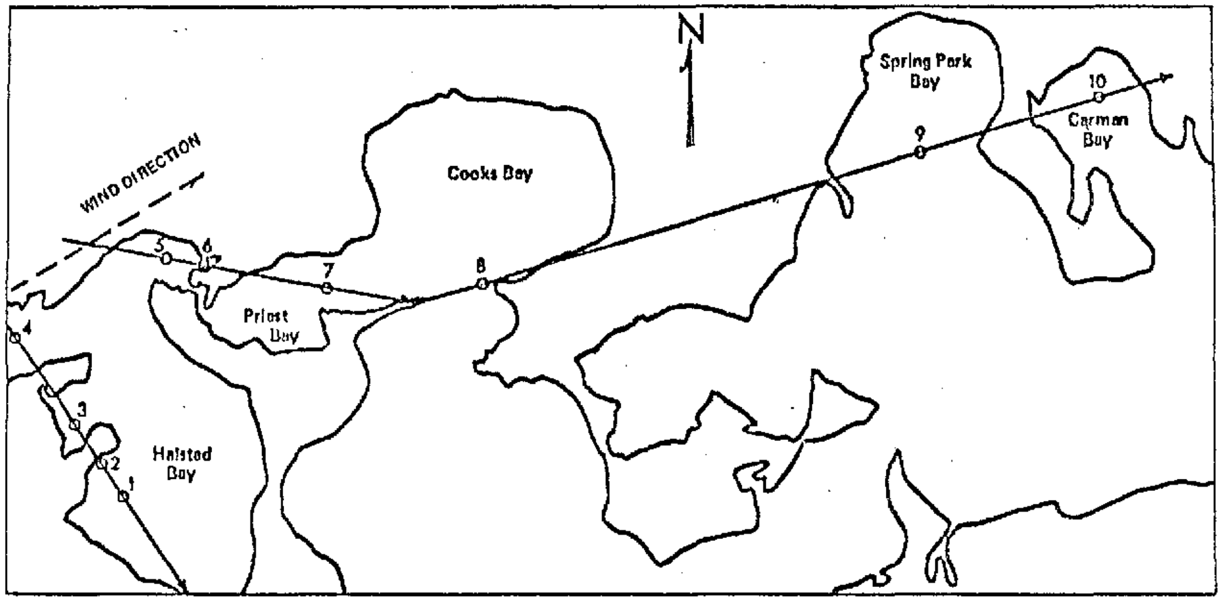


Figure 2. Location of bays, flight lines and sample points in Lake Minnetonka.

Table 1. Description of films used for overflight of Lake Minnetonka.

Film	Sensitivity	Description & Special Properties	Base Type	Nominal Base Thickness mil.	Backing
Plus-X Aerographic 2402	Panchromatic (with extended red)	Medium-speed high dimensional stability for mapping and aerial reconnaissance	ESTAR	4.0	Fast-drying
Aerographic 2424	Infrared	Reduction of haze effects & for oblique long distance photography	ESTAR	4.0	Non-gel
Aerochrome 2443	Infrared	False-color reversal film, high dimensional	ESTAR	4.0	Fast-drying
Kodacolor-X	Visible	Standard 35mm	--	--	--

Table 2. Filter specifications used during overflight of Lake Minnetonka.

Wavelength (nm)	Percent Transmittance			
	Wratten Filter			
	15	25	58	89B
400	--	--	--	--
10	--	--	--	--
20	--	--	--	--
30	--	--	--	--
40	--	--	--	--
50	--	--	--	--
60	--	--	--	--
70	--	--	.23	--
80	--	--	1.38	--
90	--	--	4.90	--
500	--	--	17.70	--
10	1.0	--	38.80	--
20	19.4	--	52.20	--
30	56.2	--	53.60	--
40	77.2	--	47.60	--
50	85.6	--	38.40	--
60	88.2	--	27.80	--
70	89.3	--	17.40	--
80	89.8	--	9.00	--
90	90.1	12.6	3.50	--
600	90.4	50.0	1.50	--
10	90.5	75.0	.41	--
20	90.6	82.6	--	--
30	90.7	85.5	--	--
40	90.8	86.7	--	--
50	90.9	87.6	--	--
60	91.0	88.2	--	--
70	91.1	88.5	--	--
80	91.1	89.0	--	.10
90	91.1	89.3	--	1.58
700	91.1	89.5	.53	11.20

Ground truth measurements were taken simultaneously with the overflight at the ten points shown on Figure 2. White bouys were located at each point to mark the flight line and to identify sampling points on the photographs for correlation of density readings and ground truth data. An estimate of aquatic vegetation density in terms of the number of stems per acre and percent of the area covered was made at each point. The number of stems per acre was estimated by randomly sampling an adjacent 1.5 square-foor area and expanding these results to an acre basis. The percentage of the area covered by aquatic vegetation was estimated by the ground truth observer.

Secchi disc depth and phytoplankton measurements were conducted at each sampling location. The secchi disc depth was determined by lowering a standard secchi disc to a depth at which it disappeared and then raising it until it became visible which was recorded as the depth. Phytoplankton population (total number of organisms) was sampled in the euphatic zone (surface to depth where light is reduced to one percent of the surface intensity which is approximately equal to the secchi disc depth times 2.67) with a plankton net. The number of phytoplankters per liter was determined by the Sedgwick-Rafter counting cell method.

Chlorophyll content was estimated by a method developed by Megard (2) using the secchi disc depth values (Figure 3). This method uses the following equation:

$$I_z = I_o e^{-z(Kw + KcC)}$$

Where:

I_o = average intensity of the photosynthetically-active radiation at the surface
z = secchi disc depth
I_z = average intensity at depth z
Kc = attenuation coefficient of chlorophyll
C = chlorophyll concentration
Kw = attenuation coefficient of water
e = natural logarithm

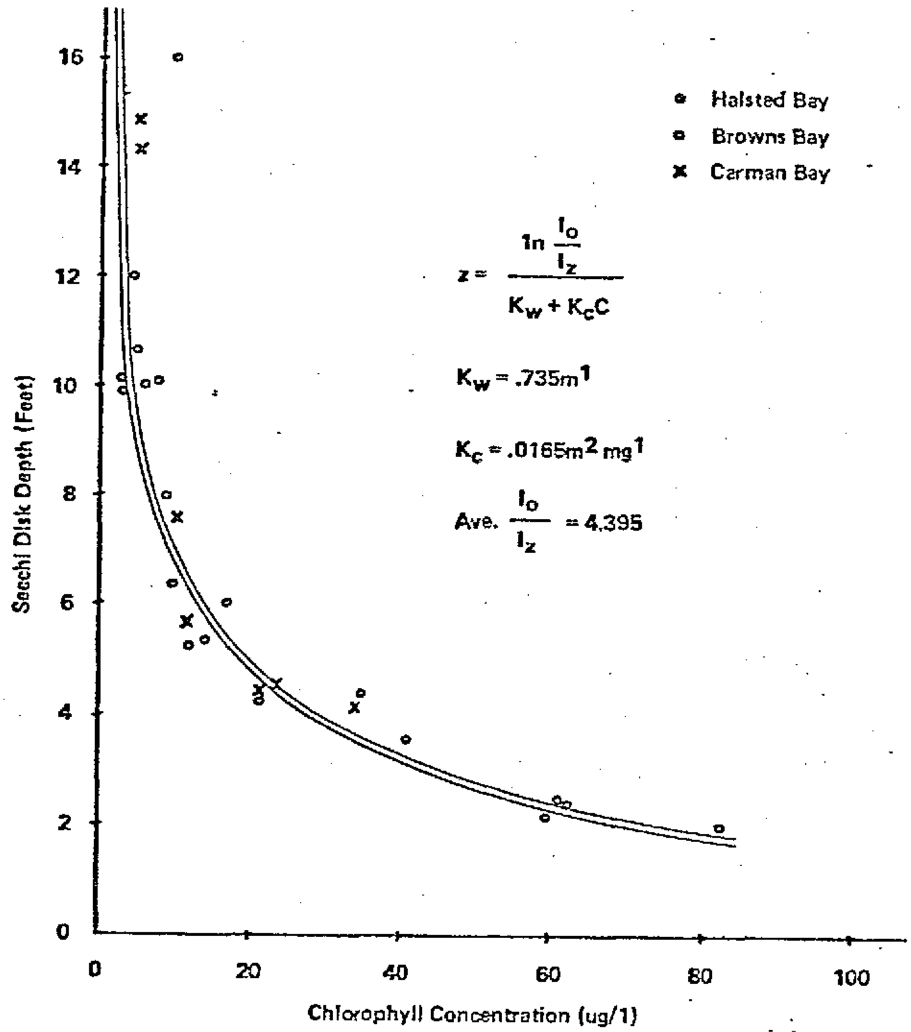


Figure 3. Chlorophyll concentration determination from secchi disc readings for the three bays sampled. Relationship developed by Megard, (1).

Rearrangement of this equation to the following form permits an estimate of chlorophyll concentration:

$$C = \frac{\ln\left(\frac{I_o}{I_z}\right) - zK_w}{zK_c}$$

Kw and Kc have been derived by Megard (1) for Lake Minnetonka and were used as constants. Since measurements of radiation intensity were not taken in the field, an average value of $\ln\left(\frac{I_o}{I_z}\right)$ was determined by the equation:

$$\ln\left(\frac{I_o}{I_z}\right) = z\,(K_w + K_cC)$$

with values of z and C taken from the graph (Figure 3).

Film densities of all film/filter combinations were determined by the VP-8 Image Analyzer.

DATA ANALYSIS, RESULTS

Film densities were correlated with secchi disc depth, phytoplankton population and estimated chlorophyll concentration. Linear and curvilinear regressions were developed utilizing various types of transformations. Also, multiple correlations were attempted to develop better prediction equations. An F-test was utilized to test for significant differences.

Film density values for aquatic vegetation were analyzed by a one-way analysis of variance for significant differences. A modified Newman-Keuls test was used to determine significant differences between species since there were missing data and the standard Newman-Keuls and Least Significant Difference (LSD) could not be used.

There were 24 possible prediction equations correlating film density of the film/filter combinations to primary productivity variables measured or estimated. Of these 24 possibilities, four significant prediction equations were found (Table 3, Figures 4-7). These results

Table 3. Prediction Equations Developed for Film Density and Primary Productivity Parameters.

Film/Filter	Scale	Correlation Factors	Prediction Equation	R^2
2402/Wr25	1:6,000	Secchi Disc vs Density	$y=4.05242+0.0124x$	.685*
2402/Wr25	1:6,000	Phytoplankton vs Density	$y=503533.56612-803.77479x$	.662*
2402/Wr25	1:6,000	Chlorophyll vs Density	$y=482.62109-0.76338x$	.705*
2402/Wr25	1:6,000	Chlorophyll[1/] vs Density	$y=181.39935.0.00042x^2$	.636*

[1/] Sample points 2 and 5 removed from estimate due to overflight slightly missing these two points and unusually high chlorophyll estimates.

* Significant at the 5 percent level.

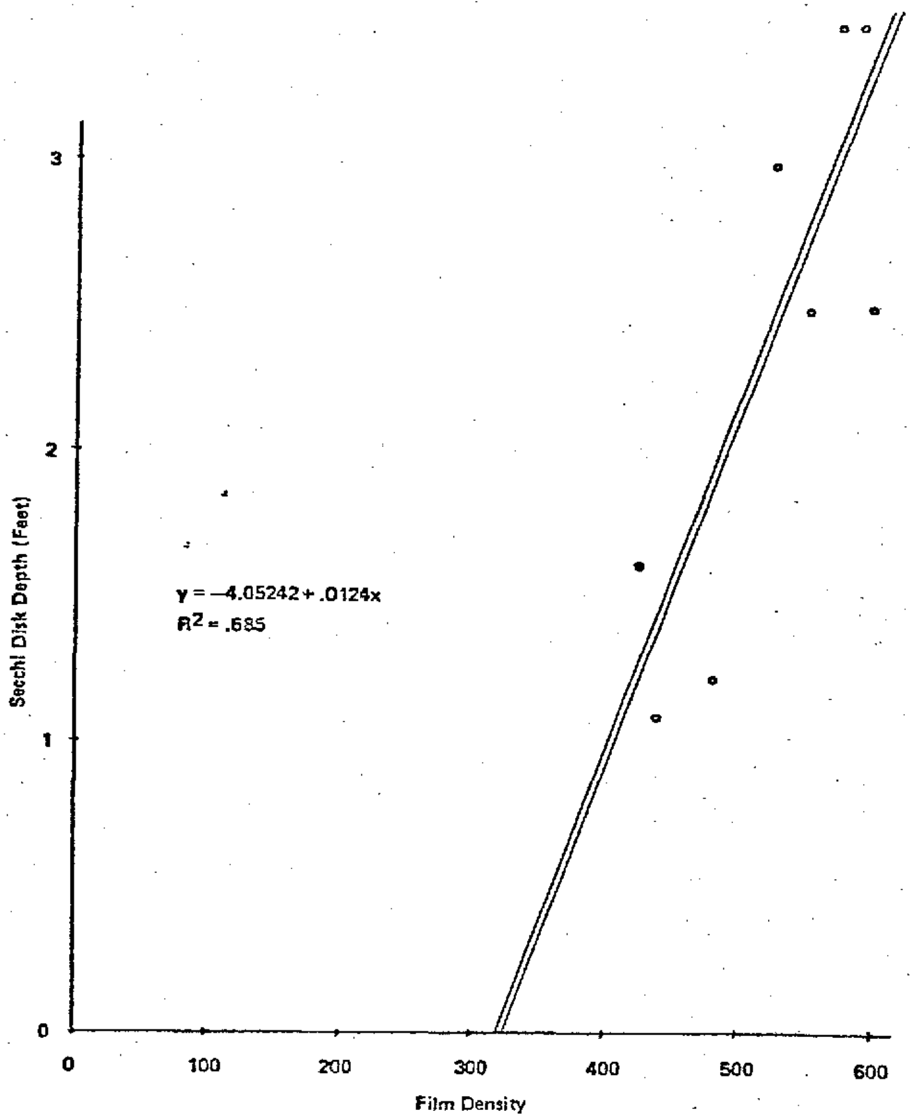


Figure 4. Secchi disc depth and film density relationship. Film/filter combination was EK Type 2402 Plus-X Aerographic/Wratten 25 at a scale of 1:6,000.

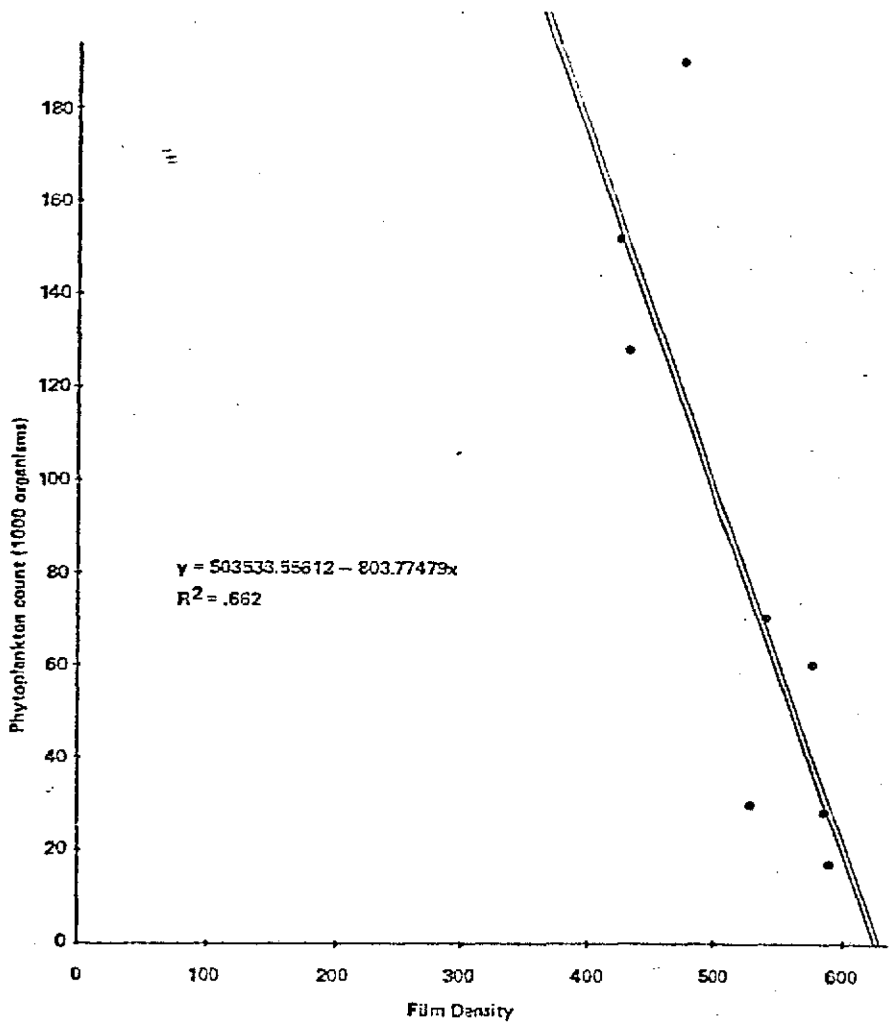


Figure 5. Phytoplankton and film density relationship. Film/filter combination was EK Type 2402 Plus-X Aerographic/Wratten 25 at a scale of 1:6,000.

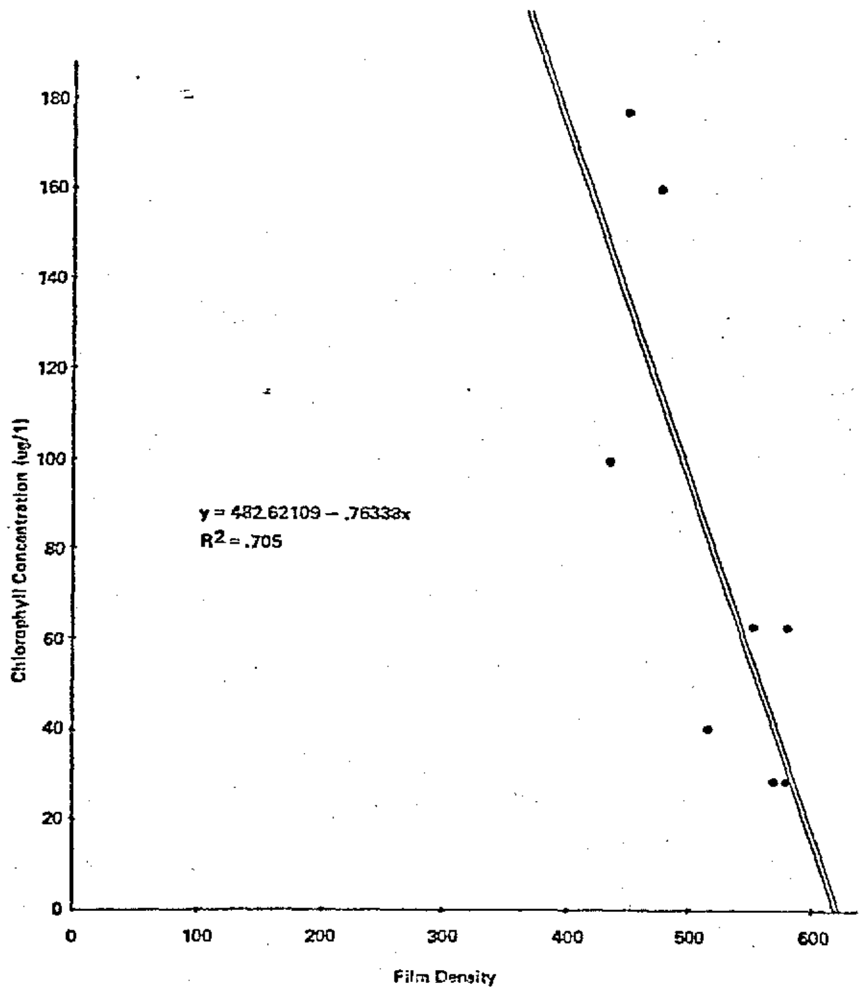


Figure 6. Chlorophyll concentration and film density relationship. Film/filter combination was EK Type 2402 Plus-X Aerographic/Wratten 25 at a scale of 1:6,000.

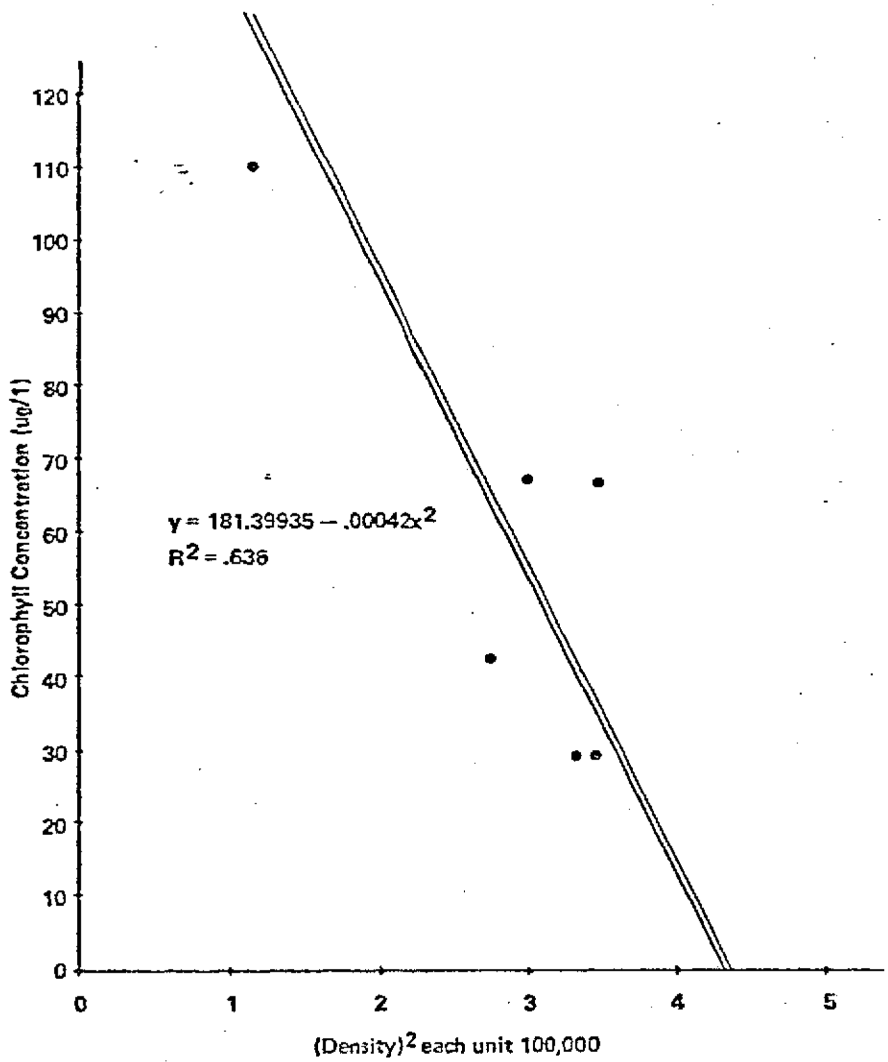


Figure 7. Chlorophyll concentration and film density square relationship with sample points 2 and 5 eliminated. Film/filter combination was EK Type 2402 Plus-X Aerographic/Wratten 25 at a scale of 1:6,000.

indicate that the significant results were obtained with 2402 Plus-X Aerographic/Wratten 25 film/filter combination at a scale of 1:6,000 in all cases. The 70mm color infrared negatives contained a flaw resembling a band across the film which invalidated density readings from this film/filter combination. This was unfortunate since previous work indicates that this film/filter combination affords an opportunity to differentiate between aquatic vegetation species.

Figure 4 depicts the relationship between secchi disc depth and film density readings. This correlation ($R^2 = 0.685$) indicates that film density can be used to significantly predict secchi disc depth between one and four feet. Since chlorophyll concentration is strongly correlated to secchi disc depth, this technique provides a valuable tool for predicting chlorophyll concentration for the purpose of monitoring water quality status and trends. This technique needs further evaluation to check its potential under other water quality conditions.

Regression analysis indicates that phytoplankton population is directly correlated with film density and can be predicted ($R^2 = 0.662$) within the range of 20,000 - 185,000 counts (Figure 5). The predominate phytoplankton genera monitored was the blue-green algae (Cyanaphyta). Prediction of nonfloating algae may not be possible, but additional tests will confirm this hypothesis.

Chlorophyll concentration and film density were significantly correlated ($R^2 = 0.705$) and the prediction equation for a range of 20 to 180 ug/l is shown in Figure 6. The higher concentration at two sampling points was due to the wind concentrating the floating blue-green algae rather than the actual concentration present at these sites (points 2 and 5). These points were removed from the analysis due to their unusually high value and the effects of wind. The analysis of the data with sampling points 2 and 5 removed still indicates a significant correlation, but a smaller R^2 value of 0.636 (Figure 7). These results indicate that remote sensing techniques can be used to predict estimated chlorophyll concentrations which will permit further evaluations of water quality status and trends.

However, it must be remembered that the estimation technique becomes limiting with either high or low secchi disc depth values.

Table 4 shows the results of the modified Newman-Keuls tests used to evaluate significant differences between aquatic vegetation species. This table contains only those film/filter combinations which significantly differentiated between species using a one-way analysis of variance test. Water lily is discernible from other species by film density readings at both 1:3,000 and 1:6,000 scales. Density differences are probably due to differences in growth characteristics since water lily is a floating species with large round flat leaves and canegrass and cattails are emergent.

During the overflight wind drift from the flight line prevented coverage of the American lotus with the 70mm film. However, data from 35mm coverage indicates that water lily and American lotus can be differentiated by film density measurements at both scales even though leaf shape is similar. Differentiation of American lotus from cattails and canegrass was only possible at the larger scale - 1:3,000. These results support in principle Strandberg's work (3) which showed that scales of 1:2,500 or larger are necessary to identify various aquatic vegetation species. The density readings resulting from 70mm Plus-X Aerographic/Wratten 58 negatives at a scale of 1:3,000 further indicate that differentiation between cattails, canegrass and water lily is more successful at larger scales. This is due in part to the film being more sensitive to reflected and scattered energy and density values are more distinguishable at larger scales.

SUMMARY, PRACTICAL IMPLICATIONS

Conclusions which can be drawn from this research effort are as follows:

1. Densities of 2402 Plus-X Aerographic/Wratten 15 film/filter combination at a scale of 1:6,000 were significantly correlated at the 0.05% level with secchi disc depth, phytoplankton population and chlorophyll concentration.

Table 4. Density Differences Between Aquatic Vegetation Species for Different Film/Filter Combinations and Scales.

Film/Filter	Scale	Average Film Density			
		Cattails	Canegrass	American lotus	Water lily
2402/Wratten 25	1:6,000	474	510[1/]	--	392
2402/Wratten 58	1:6,000	660	618	--	476
2402/Wratten 58	1:3,000	633	548	--	438
70mm Color IR	1:6,000	139	141	--	323
70mm Color IR	1:3,000	185	177	--	392
35mm Color IR	1:6,000	135	191	158	346
35mm Color IR	1:3,000	190	174	440	324

[1/] Film densities underlined by the same line are not significantly different at the 0.05 percent level.

2. Non-significant correlations were obtained between film density and primary productivity parameters with both 35mm or 70mm Aerochrome Infrared/Wratten 15 film/filter combinations. However a possible flaw in the film and/or camera opening which resulted in a dark band across the negative may have been responsible for the lack of correlation since previous work has shown partial success with this film/filter combination.
3. The scale of 1:6,000 proved to provide better correlation between film density and primary productivity than a larger scale of 1:3,000.
4. Significant differentiation between water lily and both canegrass and cattails was obtained by both 35mm and 70mm Aerochrome Infrared/Wratten 15 at scales of 1:6,000 and 1:3,000, 2402 Plus-X Aerographic/Wratten 25 and Wratten 58 at a scale of 1:6,000 and with the Wratten 58 filter at a scale of 1:3,000.
5. The greatest differentiating success for aquatic vegetation species was obtained at the 1:3,000 scale for both the 70mm 2402 Plus-X Aerographic/Wratten 25 and the 35mm Aerochrome Infrared/Wratten 15.

The principal application of this research is to provide a technique to economically assess water quality status and trends and to identify these cultural activities which contribute to the quality of a water system. The greatest need is to develop a system to monitor water quality, at least some parameters, over a large area on a periodic basis which will permit federal, state and local agencies an opportunity to carry out present and future water quality legislation. An additional benefit will be a tool for assessment of control effectiveness and ecological changes.

Results obtained in this study suggest that large scale aerial photography can be used to monitor primary productivity functions, such as secchi disc depth, phytoplankton population and chlorophyll concentrations, which are indicators of the trophic nature of a water system and the nutrient flux. Also, differentiation of aquatic vegetation by techniques employed in this research effort provides a method for evaluating trends in lake productivity.

Further refinement of techniques employed in the research effort will provide a data acquisition system which will be capable of evaluating the present water quality status and gradual trends. This system will provide an economical system for assessment of primary productivity parameters and certain aquatic vegetation species on a temporal and large areal basis. Indirect benefits may include an additional understanding of the chemical-biological-physical relationships of a water system.

LITERATURE CITED

1. Megard, R. O. 1970. Lake Minnetonka: Nutrients, Nutrient Abatement, and the Photosynthetic System of the Phytoplankton. Limnological Research Center Interim Report No. 7. University of Minnesota.

2. ________ 1972. Phytoplankton, Photosynthesis and Phosphorus in Lake Minnetonka, Minnesota. Limnology and Oceanography: 17(1):68-87

3. Strandberg, C. H. 1967. Aerial Discovery Manual. John Wiley & Sons, Inc. 249 pp.

FOREST VEGETATION CLASSIFICATION AND MANAGEMENT

Investigator: Dr. Merle P. Meyer
Institute of Agriculture Remote Sensing Laboratory
University of Minnesota, St. Paul

ABSTRACT

Representatives of the Minnesota Department of Natural Resources, the College of Forestry, Minnesota's forest industries, land commissioners of the forested counties and the U. S. Forest Service have cooperated over a period of years in developing a comprehensive plan for procurement of continuing, high quality, forest aerial photography, of Minnesota's forests. This plan was recently approved by the Minnesota State Legislature and funded for its first biennium of operation.

To insure quality coverage, the College of Forestry drafted the basic contract specifications and established a system of materials inspection. To test the possible future use of smaller photo scales (1:24,000 or 1:31,680), and thereby realize further economies of purchase and interpretation, sample test sites will be flown concurrently with the 1:15,840 current coverage in Mahnomen, Lake of the Woods, and Becker Counties in 1974.

Upon completion of these overflights, local user-cooperators will compare the relative applicability of the smaller scales of coverage in lieu of the conventional (1:15,840) coverage.

INTRODUCTION

Since coming into popular use slightly over two decades ago, aerial photography has become one of the most useful, versatile tools available to the professional forest resource manager. Its advantage over old, traditional, ground methods lies not only in a marked reduction in costs, but also in greatly increased efficiency and accuracy in performing such tasks as forest inventory, road and trail layout, forest land use classification, recreation surveys and development, watershed management, mapping, forest planting surveys, forest stand improvement, fire plans, fire suppression, and range and wildlife surveys.

But a never-ending problem in the past in Minnesota has been to secure good quality photography of the proper film-filter-season-scale combination, and achieve its replacement when it became outdated. Because of vegetation changes due to growth, harvest, change in land use, fire, insects and disease - replacement every five years would be ideal. As a practical concession to economy, however, most forest resource managers will, without complaint, accept replacement at a seven to eight year interval. More often, however, the replacement interval has been 10 years or more - which was (is) altogether too long.

Over the past twenty years, aerial photography procurement in the forested counties[1/] of the State of Minnesota (Figure 1) has been extremely haphazard. Where done, it was usually accomplished on a county-by-county basis - which meant the individual county was unable to take advantage of the materially lower unit-area costs possible with contracts for larger areas. Further, suitable expertise in the drafting of contract specifications, and in the inspection of delivered materials, was not always available - which reduced the chances of getting a suitable return for the funds expended. Also, since the photo coverage had to be paid for at the time of the overflight and could not be distributed over the life of the photography, the individual county had to raise a relatively large amount of money in a short time. The result was that photography was either not flown at all or could usually be accomplished only at intervals far greater than the desired seven to eight years.

What was obviously needed was a central procurement unit - i.e., a group or agency which could provide the necessary technical and financial leadership to insure the availability of - at the lowest possible price - good quality, recent forest resource aerial photography of the forested counties.

In the mid-1960's, the Upper Mississippi Valley Section of the Society of American Foresters established an Aerial Photography Coordination Committee to work on the problem. This committee consisted

---

[1/] Forest counties - those counties, including prairie border counties not receiving regular photo coverage of a type designed for forestry use.

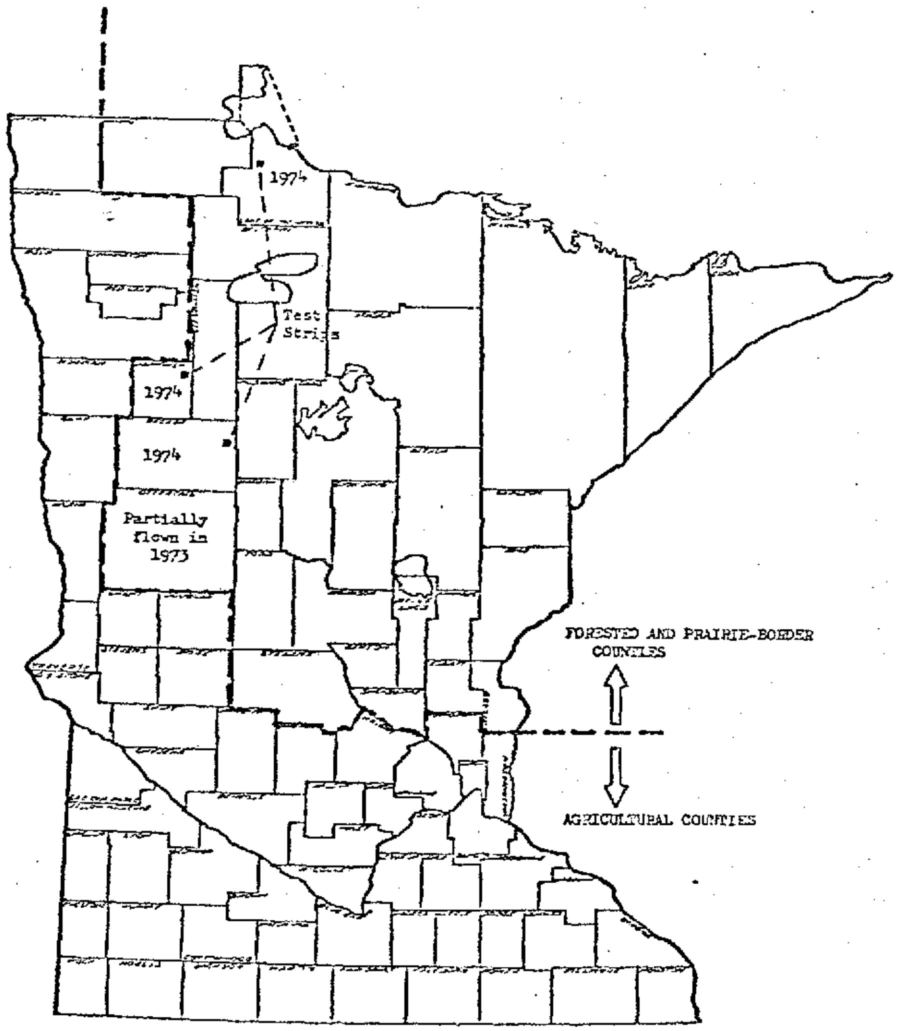


Figure 1. Map illustrating location of the forest and forest-prairie border counties involved in the comprehensive aerial photography scheme administered by the Minnesota Department of Natural Resources, Division of Forestry. The first block of four counties contracted for overflights (in progress) are indicated.

of representatives of the Minnesota Department of Natural Resources Division of Forestry, the U. S. Forest Service, the forest industries, the forested county land commissioners and the University of Minnesota College of Forestry. After almost 10 years of continuous effort on the part of this committee and its many supporters, success was achieved and, as of 1973, the Minnesota State Legislature designated the Minnesota Department of Natural Resources, Division of Forestry, as the responsible agency for a forest resource aerial photography program in the forested counties. The initial appropriation of $80,000, for the first biennium of the effort, was designated for the purchase of aerial photographic coverage only. Additional funding had been requested for the following housekeeping tasks: drafting of suitable contract specifications; establishment of a mechanism for keeping the users in the counties fully informed of the overflight schedules, photo availability and prices; and establishment of tests of new specifications (e.g., photo scales) for possible use on future photography. However, this administrative/research phase was not funded, and it was at this point, and for this purpose, that the project reported here was activated.

Although this project was funded at a significantly lower level than that previously requested from the Minnesota Legislature, it nevertheless provided the means for drafting an operational contract and specifications (1), establishment of several "piggyback" test contracts for experimental (smaller scale) overflights at the time of the regular contract overflights in three of the counties (Figure 2), and preliminary training of field cooperators.

STUDY DESIGN, DATA COLLECTION

Contract Specifications

Necessary (basic) specifications for most resource aerial photography already exist in the contracts currently used by the U. S. Department of Agriculture's Agricultural Stabilization and Conservation Service and the U. S. Forest Service. For the most part, therefore, the backbone of the specifications drafted for the Minnesota Department

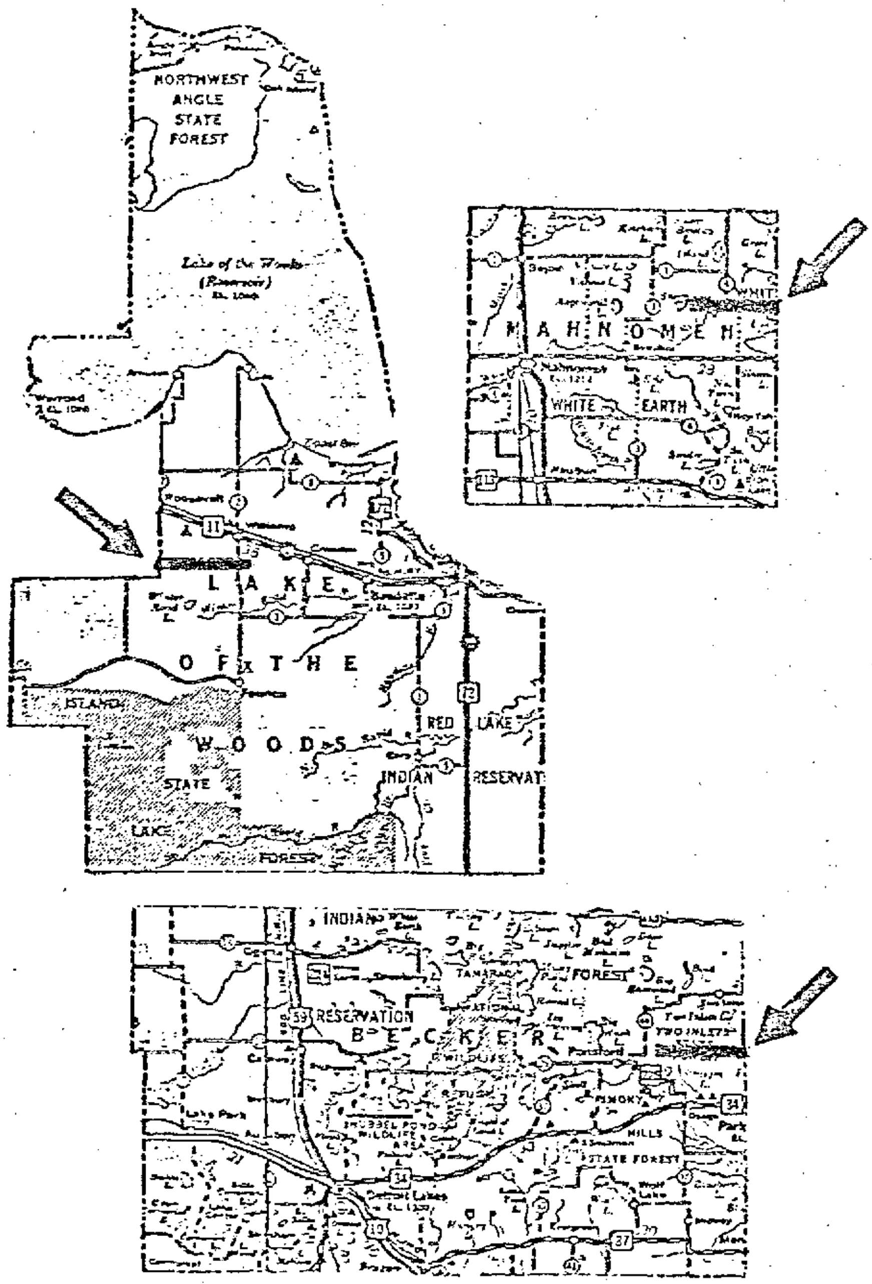


Figure 2. Location of 1:24,000 and 1:31,680 scale test strips to be flown in Becker, Lake of the Woods and Mahnomen counties in 1974.

of Natural Resources varied from these only as deemed essential to fit the local situation. However, two portions of the Minnesota specifications were, in particular, somewhat different.

Due to increasing nationwide attention being given to the utility of remote sensing for resource management (in no small part a result of NASA's Earth Resources Program) demands for aerial photo coverage have increased everywhere. So, coincidentally, have the number of individuals and firms professing an interest, and the capability, to provide aerial photographic services! Unfortunately, the possession of a suitable camera, aircraft and a crew whose (apparent) qualifications are minimal but adequate, is not in itself bona fide indication of an ability to deliver a satisfactory product - although such credentials presented may, in themselves, satisfy the requirements of a great many contract specifications currently in use. To avoid possible problems of contractor non-qualification in the preparation, and presentation, of materials for inspection and to guarantee at least a modest level of experience, the following specifications were developed:

1. Materials inspection procedures. Many of the contracts which have served usefully in their present form for many years simply do not specifically spell out the inspection procedures which are generally taken for granted by most purchasers and by the average, experienced, contractor.

Some new entries into the resource aerial photography field are either ignorant of, or prefer to ignore, normal procedures in the preparation and presentation of materials. Among the deficiencies encountered have been the following: (a) inspection prints not stripped up; (b) negatives and prints not edited; (c) reflights and rejects thrown together in a pile, necessitating time-consuming sorting on the part of the inspector; (d) no attempt made at pre-inspection by the contractor; (e) first-inspection prints delivered printed in "final" form, and (f) non-submission of final printing samples prior to the final printing of the entire job.

Even though the contractor is willing to learn and to redo that which was undone or improperly done, tremendous amounts of time are lost, the inspection costs are inordinately high and essential vegetation stages may be lost while locating possible reflight areas. What may be even worse, and has happened, is that the contractor will protest this as an item not covered in the specifications and may, subsequently, refuse to do the inspection preparation job properly without additional reimbursement. To avoid these difficulties, the following section was inserted in the contract:

> "Preparation for Inspection. Inspections will only be made using contact prints from properly edited negatives. Prints of such quality that the terrain is not readily discernable or from negatives with grease pencil or other temporary markings are not considered suitable for inspection purposes. Prints shipped for inspection purposes will be arranged in order by flight strips and separated by a paper band placed around each set of prints. Within each flight strip, the prints shall be arranged in numerical sequence from north to south or from east to west.
>
> Flight strips shall be prepared in the conventional manner for inspection: (a) the prints shall be fastened together in proper overlap fashion with titles showing, (b) tape shall be the preferred manner for fastening the prints together, (c) regardless of the fastening medium used, it shall be possible to check alignment and overlap without unfastening the prints, (d) the photos, and lines, shall not be stapled or otherwise fastened to any surface (board, wall, table), and (e) the Contractor shall be prepared to indicate to the purchaser, at the time of inspection, any portions of the materials to be inspected which are known not to meet contract specifications and such portions are to be so labelled with grease pencil on the photographs.
>
> Inspection Phases. Inspection shall consist of three phases.
>
> Phase I inspection for coverage; i.e., endlap, sidelap, adherence to proper flight path, scale, stereoscopic coverage to flight line terminuses, absence of clouds, absence of cloud shadows, etc. This phase shall be made using vertical 9x9-inch or mini-prints provided by the Contractor for that purpose. An attempt to provide final delivery quality prints at this stage will be at the Contractor's risk.
>
> Phase II is an inspection of the vertical negatives for proper density and contrast, stains, reflections, detail, ground movement, etc., and for the negatives physical quality; i.e., freedom from rips, tears, scratches, etc.
>
> Phase III is for the quality of the delivered vertical prints, photo index negatives, photo index prints, and a final inspection of the vertical negatives for physical quality."

2. Evidence of Contractor Qualifications. Beginners in the aerial photography field have usually had experience, albeit usually of the short-line, spot-coverage type of coverage. Many have not, unfortunately, experienced the difficulties of flying systematic coverage of large areas - particularly where long lines, small alignment tolerances and lack of navigational features typical of many forested areas are involved. To assure a modicum of experience, therefore, the following specification was inserted in the Minnesota contract:

> "Statement of Facts. The Bidder shall submit a certified statement of facts listing equipment, names and qualifications of pilot and photographer (i.e., training, experience), and general facilities. Statements shall be certified by a responsible officer or owner of the firm and shall represent a true statement of the facts submitted as of date of bid. In addition, in order to substantiate the stated ability to satisfactorily perform the tasks required by this advertisement, the Bidder shall also be required to furnish evidence of prior (satisfactory) completion of a similar job of forest aerial photography; such information to include the name and address of the involved purchaser, the location of the project area and the specifics of the aerial photography provided that purchaser."

It has been argued that this specification is too restrictive and bars competition. This is possibly true to some extent, however, unfortunate experiences on the part of a number of Purchasers have shown all too clearly that on-the-job training on difficult aerial photography missions can be extremely costly - to that Purchaser! One acceptable alternative would be for the tyro aerial photography firm to, on its own initiative and at its own expense, fly a typical area at standard specifications in order to provide acceptable evidence to potential Purchasers (as well as to himself) of an ability to provide the services required.

Future Specification Tests

Past investigations by the College of Forestry (2) indicate that, with proper photographic specifications, suitable training of field users, and with improved viewing equipment - smaller photo scales than the 1:15,840 currently in use, can be utilized. Should it be possible, for example, in the next biennium, to fly multi-county blocks with 1:31,680 scale photography instead of 1:15,840, the cost of procurement would be cut about 40% - in view of the fact that this scale differential would result in 50% less flight lines and 50% less exposures per line - with a total reduction in required exposures of 75%. This would also materially reduce the use cost in that only one-fourth as many photographs would have to be handled and interpreted, less storage space would be required and replacement costs would be less.

If it is possible to shift from large to smaller scales of photography and realize economies of use without information loss - a change in current photo interpretation techniques and equipment will almost certainly have to be involved. Traditionally, makeshift lighting and working surfaces, coupled with a 2X magnification pocket stereoscope, are the traditional tools of the forest resource photo interpreter -- and it must be said that they have, on the average, proven themselves remarkably proficient with these modest facilities. It was felt, however, that a shift to smaller scales of photography could be successfully accomplished only if the total photo interpretation process were upgraded in terms of interpreter skills, lighting quality, working facilities and viewing instrument capabilities. It was recognized from the outset, therefore, that personnel training and providing good quality, modern photo interpretation equipment would be fully as essential to this study as the photographs themselves.

Due to many delays, the final contract for Becker, Lake of the Woods, Ottertail and Mahnomen counties was not let until late summer, 1973 - thus eliminating any possibility for obtaining either the county coverage or the test flights during that year. Another (similar) College of Forestry pilot study had, however, been previously set up and flown on several sites in Itasca County. These Itasca County test areas involved the cooperation of users from the U. S. Forest Service, Minnesota DNR, Itasca County, Blandin Paper Co., Deer River Lumber Co., Boise Cascade and the Soil Conservation Service. Remaining funds from this (NASA) project were subsequently applied to the support of the ongoing Itasca County Study. This support took the form of cooperator

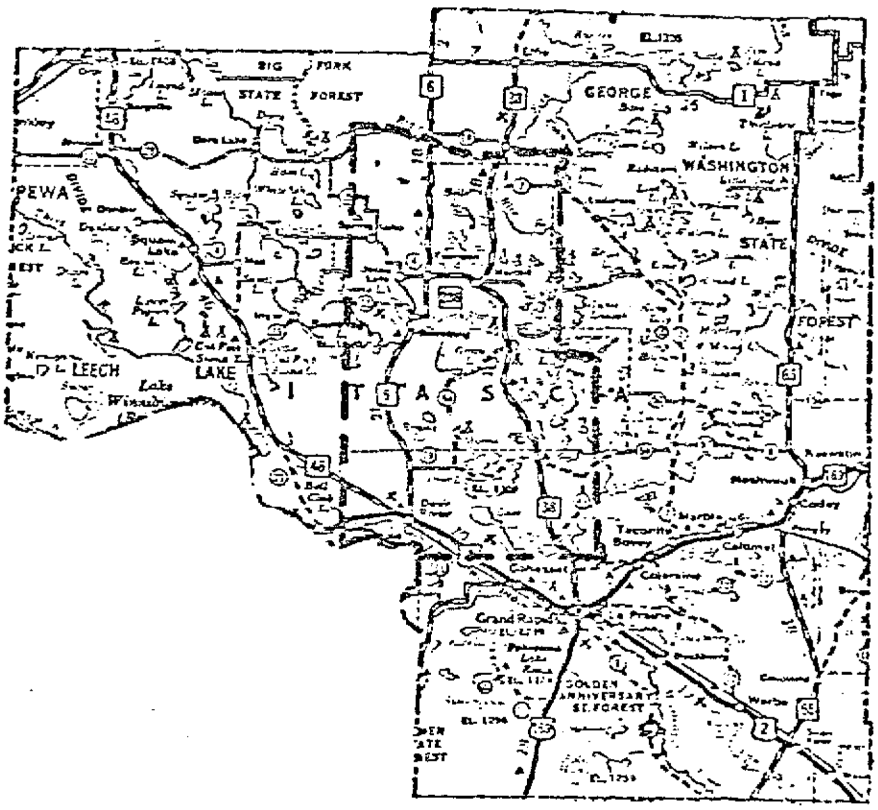


Figure 3. Itasca County test site flown in 1973 which is now under study by cooperators from the Minnesota DNR, U. S. Forest Service, county land commissioner's office, forest products industries, Soil Conservation Service and the U. S. Geological Survey.

training, purchase of suitable 3X binocular mirror stereoscopes and portable lights and fabrication of special photo interpretation boards (tables) for use with the mirror stereoscopes.

Cooperator comparisons on the Itasca County study are still in progress.

DATA ANALYSIS

Centralized Forest Aerial Photography Procurement Plan

1. Purchase Costs. The first block of forested counties to be successfully bid and let substantiated the assumption that the plan would result in significant savings over previous county-by-county purchases. This multi-county block of some 16,000 square miles was contracted at a price, to the DNR Division of Forestry, of slightly over $5.00 per square mile. Individual users in the Counties (identified in the contract) will be able to purchase prints at a very nominal price (averaging about $1.00 per print). Comparatively, a single county contracting for coverage "on its own" would have to pay about $8.00 per square mile for the same coverage. By the same token, the purchase of additional sets of prints (by them or other users) would probably run from $1.30 to $1.75 per print on a county-by-county basis. A summary of the comparative costs on the 4-county block (Ottertail, Becker, Mahnomen and Lake of the Woods) is indicated in Table 1.

2. Financial Benefits in Resource Management. It is not difficult to ascribe cost savings to the multitude of users from the standpoint of the actual contracting for, and purchase of, the aerial photography. It is difficult, however, to estimate the financial benefit of good quality, recent, aerial photography in lieu (often) of the existing fair-to-poor quality, old (often beyond the point of usefulness) coverage available in some of the counties. Unquestionably, in any county with an active resource program, it will mean greatly increased data quality and quantity, and tremendously reduced travel and field time on the part of those involved in actual ground information gathering and resource management

Table 1. Comparative aerial photography purchase costs applied to a 16,000 square mile forested county area in Minnesota

Item	Estimated cost: Old county-by-county system	Estimated cost: New large-area purchase system	Projected savings
Cost of original coverage and index mosaics	$154,000	$80,000	$74,000
Cost of additional set of contact prints	19,200	16,000	3,200

decision making. As an example, for a county with 10-12 year old, poor quality, photography, the availability of new, good quality coverage will mean a tremendously accelerated resource data collection system and an efficient, expanding, data base. The professional capabilities of all involved management and field personnel will be increased many times and it would not be unrealistic to assume that a sizable county in this situation would realize immediate benefits in the range of $5,000 to $15,000 per year. <u>This would not be cash left over but would represent the increased worth of the services performed for the budget available</u>. These benefits would be further expanded by the desirable economic benefits realized by those served - forest industries, recreation, agriculture, wildlife management and many others.

SUMMARY, PRACTICAL IMPLICATIONS

Centralized Aerial Photography Procurement and Quality Control

A 10-year cooperative effort on the part of the Minnesota Department of Natural Resources Division of Forestry, the Minnesota forested county land commissioners, the Minnesota forest industries, the U. S. Forest Service and the University of Minnesota College of Forestry has resulted in the development of a plan for continuing forest resource aerial photography for Minnesota. This plan has now been financed on a start-up basis and implemented by the Minnesota State Legislature. The results will be to assure forest resource managers of continuing (every 8 years) good quality aerial photography (as a result of sound specifications and carefully controlled inspections) at the least possible cost. Two types of economic gains will actually accure: (a) savings in initial purchase, and (b) given the same personnel and budget structure, the improved quality of aerial photography will greatly extend the attainable scope of quantity and quality of resource data and management decision capability.

For example, assuming 8 counties with an average area of 2,000 square miles and an increased operational efficiency worth $5,000/year (<u>very</u> minimal), as a result of better available aerial photography, the total worth of the program to the county land commissioners' offices and their immediate service recipients would be approximately as follows for the biennium:

Savings on aerial photography	$77,000
Additional user copy sets (2 per county)	7,500
Value of increased service efficiency due to availability of photography ($5,000/county/year)	80,000
	$164,500

It must be borne in mind that the DNR, Division of Forestry, also benefits from the new photography. As managers of the largest single forest land ownership in Minnesota (over 4,000,000 acres) the affects of the aerial photographic management tool upon their production for the period (timber harvest regulation, recreation, reforestation, road and trail planning, fire prevention and control, etc.) would be a sizable amount and additional to the figures estimated above. Other important users, such as the forest products industries, would also realize substantial benefits.

Improved Forest Aerial Photography Specifications

Tests are still in progress.

LITERATURE CITED

1. Meyer, M. 1973. Forest Aerial Photography Contract Specifications - Minnesota Department of Natural Resources, Division of Forestry. Mimeo., 15 pages.
2. Ulliman, J. and M. Meyer. 1971. The feasibility of forest cover type interpretation using small scale aerial photographs. Prcdngs., 7th Int'l. Symp. on Remote Snsng. of Environ. Willow Run Lab., Inst. Tech., Univ. Mich., Ann Arbor.

DETECTING SALINE SOILS IN THE RED RIVER VALLEY, MINNESOTA BY REMOTE SENSING TECHNIQUES

Investigators: Dr. Richard H. Rust
Department of Soil Science
University of Minnesota, St. Paul
Mr. Bruce H. Gerbig
Department of Forest Resources Development
University of Minnesota, St. Paul

ABSTRACT

During this second year of the investigation of the saline soil problem in the Red River Valley, effort was concentrated on a detailed examination of 1:40,000 scale color and color IR photography taken in early August, 1973, along the two 10-mile transects in Kittson County. On a portion of one transect additional imagery was obtained at a scale of 1:10,000. On the basis of the photo interpretation coupled with ground truth observations, it is concluded that about 65 percent of the landscape is saline-affected. Photo interpretation of fallow areas (about 20 percent of the areas) cannot be made with any confidence. Cost figures for 35mm imagery were developed. For areas of 25 to 100 square miles - obtaining 35mm photography seems the most economical and will be used in subsequent imagery and analysis.

INTRODUCTION

As a result of the first year of investigation on this study, it became apparent that color infrared imagery taken in late October and subjected to image analysis was of limited value in delineating saline conditions on essentially bare (plowed) soils. Since severity of the saline condition is related to the amount of small grain growth and hence residue, the amount of residue evident on the (usually) disc-plowed fields becomes indirect evidence of salinity. Thus the effort in 1973 was to obtain imagery at a time more correlated to "peak of green", or maximum growth expression. Here some compromise is necessary in respect to wheat and barley since planting time and/or growth rates are not usually coincident.

AREA DESCRIPTION

The study area has been described in a previous report (1). The 1973 growing season was rather ideal for small grain. Spring planting was completed by about May 15. Much of the wheat planted consisted of newer, short-strawed varieties which respond to nitrogen fertilization. Yields were significantly higher than in most previous years. The acreage planted to wheat increased slightly over 1972.

On the Clow transect line 18 to 20 percent of the tillable land was fallow; in the Davis transect line about 30 percent was fallow. The higher percentage of fallow land along the Davis Transect is a reflection of a higher percentage of saline-affected soils. (But all fallow land is not saline-affected).

STUDY DESIGN, DATA COLLECTION

Progress of Investigation. 1973 investigation efforts were concentrated on obtaining photography of the two east-west transect lines during the "peak of green" period. Due to favorable spring planting conditions, this optimum time period fell in late July. Coverage was actually obtained on August 3, 1973, using the 70mm quadricamera system. Aerochrome Infrared Type 2443 and Ektachrome MS Aerographic Type 2448 films were used to acquire complete coverage of the transects at a scale of 1:40,000 and additional 1:10,000 coverage of Sections 5 and 8, Davis township was also obtained. B&W multispectral imagery was omitted because of its marginal value in the 1972 investigation and the color film was substituted in its place.

Ground Truth Observation. A series of observations was made in August, 1973, along both transect lines. Soil samples were taken from areas showing various degrees of saline effect on growing small grain and from some fallow areas. The results of conductivity determinations are shown in Table 1. Paired samples were taken in several instances - one sample from a presumed normal growth area and a second from a reduced growth area. In all cases of sampling from 1973 grain crops the photo interpretation was supported by the laboratory analyses.

Table 1. Conductivity values of comparison soil samples taken at selected points along Clow and Davis transects, August 30, 1973.

Sample	Location (Twp. Sec.)	Culture	Conductivity (mmhos)
*C1a	St. Vincent 11,	Fallow	0.8
C1b	W 1/2 SW 1/4	Fallow	0.4
C2a	Richardson 8	Oats, normal	0.7
C2b	NE 1/4 NE 1/4	Oats, poor	4.8
**D1a	Davis 3	Barley, normal	1.1
D1b	NW 1/4 NW 1/4	Barley, poor	10.0
D2a	Davis 5	Wheat, normal	0.9
D2b	SW 1/4 SW 1/4	Wheat, no growth	30.0
D3a	Davis 9	Barley, poor	8.8
D3b	SW 1/4 SW 1/4	Barley, no growth	10.6
D4a	Davis 8	Barley, Lt. residue	5.6
D4b	SE 1/4 SE 1/4	Barley, no growth	11.0
D5a	Davis 9	Barley, normal?	2.2
D5b	SW 1/4 SW 1/4	Barley, no growth	15.4
D6a	Davis 9	Wheat, poor	3.8
D6b	SE 1/4 SE 1/4	Wheat, no growth	24.1

* Clow transect line E-W
** Davis transect line E-W

Table 2. Summary of photo interpretation of saline-affected fields along the Clow and Davis transect lines, 1973.

Line	No. of fields observed	Percent having damage rated Severe	Moderate	Slight	Not Discernable
Clow	208	32	30	1	37
Davis	176	21	23	3	53

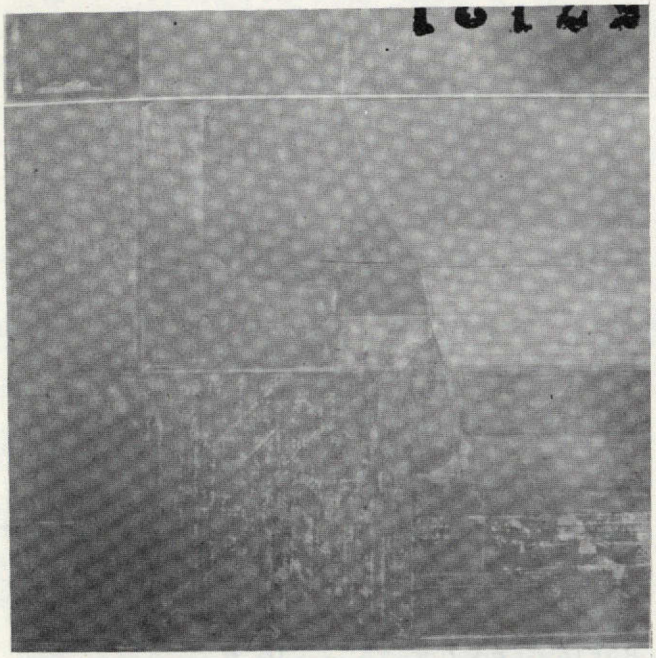


Plate A

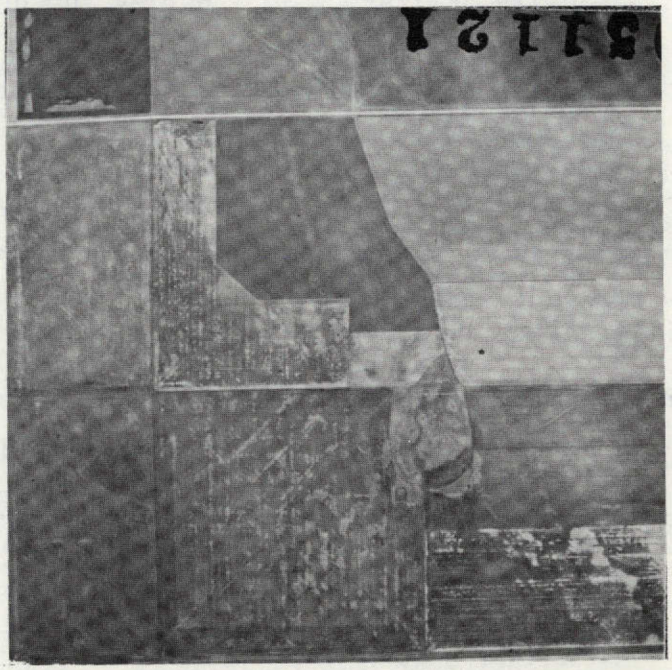


Plate B

Figure 1. Example of portion of color (Plate A) and color infrared (Plate B) photography taken along Davis transect (Sec. 8, T159N, R48W). Original scale 1:40,000, shown 2X. Exposed August 3, 1973. Note that about one half of the section is fallow. Note irregularly-shaped field in NW1/4. About 80 acres planted to barley showing severe saline effect, particularly in color infrared.

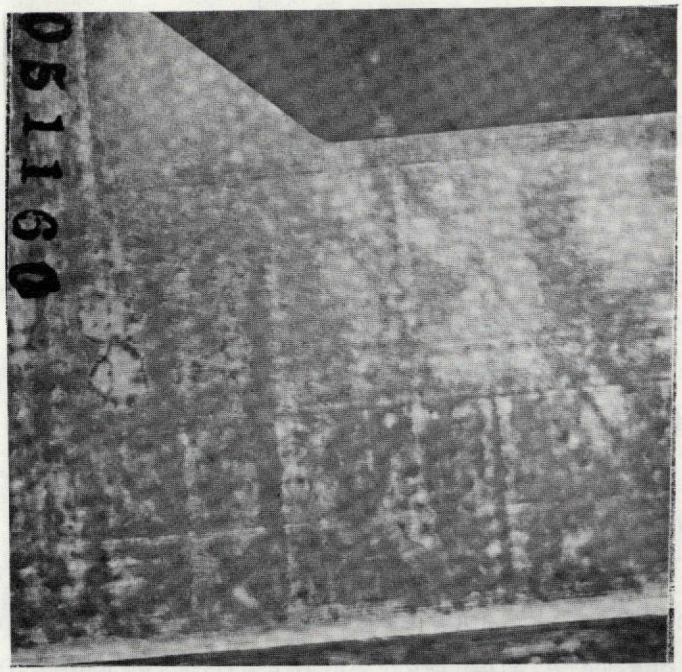


Plate A

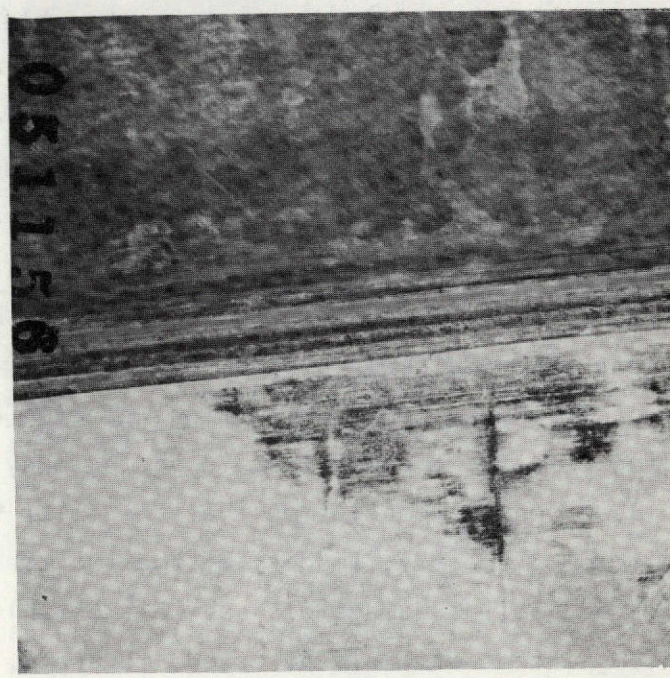


Plate B

Figure 2. Examples of portion of color infrared photography taken along Davis transect (Sec. 8, T159N, R48W). Original scale 1:10,000, shown 2X. Portion of barley field as noted in Figures 1 and 2 on Plate A. "Diamond" and "Square" patterns relate to cultivation and seeding practices. Gradation of saline effect clearly evident. Plate B exhibits area along south edge of Section 8 and north edge of Section 17. The presence of Kochia is evident in a saline area.

DATA ANALYSIS

Interpretation and Analysis of Imagery. To simplify the interpretation and analysis of the color and color infrared imagery, the work was divided into two parts. The first job was to compare the two film types for relative effectiveness. A subjective analysis was used and the color infrared film was determined to be superior for the following reasons: (1) crop vigor classes were easier to determine, and (2) crop-saline area boundaries could be determined under a wider range of conditions.

Crop vigor variations were determined by visual analysis of the imagery over a light table. The color infrared film proved superior in that a great variation of red to pink tones was evident (Figure 1, Plates A and B(. Spatial distributions were also much easier to determine. The color film was not able to show crop vigor conditions to the degree that the color infrared film did because the color variations were very restricted. Crop-saline boundaries were also examined in a similar manner and again the color infrared film was superior.

The second task was to determine how much more useful the large scale photography was over the small photography. In a subjective laboratory analysis it was concluded that the large scale photos were more useful than the small scale photography in showing small bare spots that indicate a general salt problem and kochia was more easily distinguished from other vegetation by its bright scarlet color, but for broad scale mapping efforts, the small scale photography was adequate.

Based on the conclusion that the color infrared imagery was superior to the color imagery, imagery of the two transects was studied and interpreted. Saline damage classes were established as follows: severe, more than 50 percent of field affected; moderate, 25 to 50 percent; slight, less than 25 percent affected. Table 2 summarizes this photo interpretation. It should be noted that 37 percent of the fields along the Clow line and 53 percent of fields along the Davis line were not readily interpretable. As previously noted about 20 percent of the fields were fallow on the Clow line, and 30 percent on the Davis line. It is very probable that most of these have saline-affected areas. It further suggests that additional imagery in subsequent seasons would be necessary for evaluation of the total landscape.

Cost Estimates for 35mm Photography. The 35mm Aerial Photography System developed by Meyer, et. al. (2) is an operational system that can be used for obtaining spot coverage of localized saline problems and limited area coverage. A working manual of operations (3) summarizes the necessary considerations and steps to take from flight planning to image analysis.

Since the most important feature of the 35mm Aerial Photography System is its adaptability for use at the local level, it was determined that cost estimates should be prepared for commonly used film/scale/area of coverage combinations.

In considering and calculating these costs, the costs were broken down into these basic factors: (1) aircraft and pilot, (2) photographer, (3) aerial photography equipment and (4) film and processing. Cost figures (or estimates) were then derived for each of these factors (4).

These factors were then combined to estimate typical project cost figures. The first and most common use of the 35mm Aerial Photography System is to obtain spot coverage of a particular resource feature. This could be a feature that defied description attempts from 9x9-inch aerial photography or it could mean monitoring a small area that is undergoing rapid change. The very nature of this form of use makes cost/area figures meaningless and points toward the use of cost/hour figures. The second use of the system is to obtain area coverage. An example of this coverage could be photography of an area with severe saline soil problems. This type of coverage makes cost/area figures possible.

Spot Coverage Costs. Calculations for cost/hour figures for spot coverage include the following:

1.	Aircraft and pilot	\$30.00/hour
2.	Photographer salary	5.00/hour
3.	Aerial photography equipment	5.50/hour
4.	Film and processing costs	Variable
		\$40.50/hour + film and processing

Table 3. Approximate cost per square mile for 35 mm aerial photography by film type, film scale and area of coverage.

Film	Film Scale	Area of Coverage, in square miles			
		25	50	75	100
		Slide Film			
Ektachrome IR	1:10,000	$31.43	$31.32	#30.92	$30.30
Ektachrome IR	1:20,000	10.36	10.24	9.93	9.68
Ektachrome IR	1:30,000	6.01	5.84	5.53	5.40
Ektachrome IR	1:40,000	4.01	3.98	3.73	3.56
		Print Film			
Kodacolor-X	1:10,000	53.85	53.63	52.92	51.88
Kodacolor-X	1:20,000	16.39	16.17	15.68	15.28
Kodacolor-X	1:30,000	8.97	8.73	8.26	8.06
Kodacolor-X	1:40,000	5.75	5.69	5.32	5.07

Area Coverage Costs. Area coverage costs were estimated for the following film/scale/area coverage combination:

1. Film types - Ektachrome IR and Kodacolor-X.
2. Photo Scales - 1:10,000, 1:20,000, 1:30,000 and 1:40,000.

Table 3 summarizes the approximate costs per square mile for 35mm aerial photography as film type, film scale and area of coverage are varied. Gerbig (4) shows the procedure and sample calculation used to derive these figures. Note how costs decrease as the photoscales become smaller and how increases in area coverage result in only slight decreases in costs. Also note how color print film for the same area and scale specifications is more expensive than positive transparencies. Actual costs will vary according to local conditions.

SUMMARY, PRACTICAL IMPLICATIONS

Summary

1. Color infrared film exposed through a Wratten 15 filter was found to be superior to true color film for delineating saline soil conditions.

2. Scales in the 1:40,000 range were found to be adequate in delineating photography in the 1:10,000 scale range of several small areas of known salt problems to "set the tone" for crop vigor and kochia development.

3. 70mm vertical color infrared photography is suitable for delineating saline soil areas. The 35mm photography system developed by Meyer, et. al (2), is also suitable and cost estimates using this system were prepared.

Practical Implications. Saline soils affect substantial areas of the Red River Valley. Interest in these soils has increased due to higher grain prices as a result of the world shortage of grains. Remote sensing techniques that can be applied on the local level promise the county extension and technical assistance people a tool to aid them in their mapping and rehabilitation efforts.

LITERATURE CITED

1. Rust, R. H. and B. Gerbig. 1973. Detecting saline soils in the Red River Valley, Minnesota, by remote sensing techniques. Chapter 4. Inst. Agr. Remote Sensing Lab. Rpt. 73-1.

2. Meyer, M. et.al. 1973. A 35mm aerial photography system for forest and range resource analysis. U. Minn. Coll. for Res. Note 240. 4 pp.

3. Meyer, M. 1973. Operating Manual. Montana 35mm aerial photography system (lst revision). Final Rep., USDI-BLM MSO proj., IARSL Res. Rep. 73-3. 50pp.

4. Gerbig, B. 1974. Use of remote sensing techniques for the detection and assessment of saline soils in the Red River Valley. Unpublished major paper. U. Minn. Coll. For. 40 pp.

USE OF ERTS IMAGERY TO ASSIST IN SNOWMELT FLOOD PREDICTION

Investigators: Mr. James Pennaz and Dr. C. Edward Bowers
Department of Civil and Mineral Engineering
University of Minnesota, Minneapolis

The objective of this study is to determine whether ERTS Imagery can be useful in the analysis and prediction of snowmelt floods, particularly in the Upper Midwest portion of the United States.

In recent years, severe floods have occurred in the upper Midwest. In 1965 and 1969, spring floods in this region caused primarily by snowmelt, resulted in total damages estimated at 300 million dollars. While early warning and emergency flood protection works resulted in saving of about 100 million dollars much work remains to be done to properly evaluate the flood potential and probable flood magnitudes in the late winter and early spring months.

One of the primary problems associated with spring flood prediction is the determination of the accumulated water content of snow on the ground. With small research watersheds this is not too difficult if the area is easily accessible. However, when predicting floods in the Minnesota River Basin (16,200 square miles) or the Upper Mississippi River Basin (62,800 square miles in Minnesota) the problem becomes much more difficult. The National Weather Service and the U. S. Army Corps of Engineers obtain field samples during the late winter if the depth of snow indicates the possibility of severe floods. However, the number of observations is such that on an average each one represents about 2,000 square miles. In addition, the observer is presumably attempting to obtain an average depth for his area; as some fields may be bare and other areas have several feet of snow the problem is difficult.

Snow observations in this area are usually obtained by forcing a metal tube down through the snow, placing a shovel or other device under the bottom of the tube and then lifting the tube and snow out for weight determinations. The snow may be dumped into a plastic bag for weight determination or may be weighed with the tube. The end result is the weight of the water content of the snow and it is usually expressed in inches of water. An observer may take a number of observations at one location which are then averaged for a water content value at that site. He does not provide a separate figure of percent of snow covered area.

Flood forecasters in the National Weather Service and the Corps of Engineers usually prepare a flood forecast for Minnesota on or about March 15. This is based on a map showing the water content of snow for the state. Figure 1 shows lines of equal water content for a portion of Minnesota on 6 February, 1973.

As noted in a preceding report, lines of equal water content of snow were drawn, based only on field measurements. After receipt of ERTS Imagery for this period, it was obvious that the lines were in error, just by visual inspection of the prints. After revising the lines, it was noted that the lines of water content were changed by 1 inch over about 4,000 square miles.

To evaluate this effect, a mathematical simulation model of the type used in flood forecasting was utilized. The model had been fitted to 15 watersheds in the Minnesota River Basin, as part of another research project. Figure 2 shows computed and observed flood flows for one watershed, the LeSueur River for 1969. It was operated with coefficients fitted for 1965 and 1969, and with precipitation, temperature, dewpoint and solar radiation, all for the 1,100 square mile LeSueur watershed for those years. However, the accumulated water content of snow as of March 1 for those years was varied by 1 inch steps above and below the actual content for the respective years. Usually, with a total water content of 1.5 inches or less (at the time of the spring melt) major flooding will not occur in most Minnesota streams.

In 1965 the average water content of snow in the LeSueur watershed on March 15 was about 2.63 inches. This produced a flood peak at the gaging station near the outlet of 22,000 cfs, as shown in Figure 3.

In 1969 the average water content of snow was 5.63 inches but the flood peak was only 10,920 cfs, a severe flood but not nearly as bad as the one for 1965 (Fig. 2).

Taking the peak flow for a series of runs of this type, the results are plotted in Fig. 3 with peak flow as a function of average water content of snow for the watershed. The results indicate that for 1965 one inch of water content changes the peak flood of the LeSueur River by about 6,700 cfs, a very significant amount. In 1969 the change due to water content change of 1 inch produced a change of about 2000 cfs in peak flow. The difference is due primarily to (1) more severe frost penetration in 1965 and (2) a different temperature sequence during the melt period.

Following the above analysis of the 1973 data, the following research plans were made for 1974:

1. Make several field trips during the late winter (February and March) to obtain ground truth relative to water content of snow and percent snow cover. These data would be used to supplement data obtained from the Federal agencies.
2. Make plane flights over a selected area, the LeSueur watershed, on about February 28, March 15 and March 31, taking pictures which would assist in evaluating the percent snow cover and would be used for comparison with ERTS Imagery.

The above plans were based on the assumption that the spring melt would normally occur during the last two weeks in March. As is frequently the case, the weather did not follow "normal" patterns and the melt occurred about March 1-5. As a result, both field measurements and aerial photographs were somewhat curtailed.

Figure 4 shows the measured water content of snow on February 19, 1974 over central Minnesota; data were obtained by observers at each of about 34 locations. These were supplemented by field measurements as part of this study on 16 February, 28 February, 3 March and 7 March. On Fig. 4, the NASA Project observer data for 16 February are underlined. As part of this study, both aerial and ground photographs were taken and estimates made of the percent snow cover as well as water content.

Figure 5 shows initial field data for 19 February 1974 with estimated lines of equal water content superimposed.

Figs. 6 and 7 show the ERTS Imagery for South Central Minnesota (22 February, 1974, NASA ERTS-1579-16275-401 and 23 February, 1974, NASA ERTS E 1580-16334-401). Referring to Fig. 6, the Minnesota River joins the Mississippi at the dark area near the center of the print. Comparison of these images with the field data indicated that (1) the lines of equal water content of Fig. 5 were in error in some areas and (2) some of the field data were obviously in error; of major concern was the area near Mankato where the initial field data disagreed with the project data by about 1.1 inch and were obviously in error. Figure 8 shows the revised curves after study of the ERTS Imagery. Significant changes (up to 1 inch) occurred over an area of about 5,000 square miles.

To assist in the evaluation of the water content of snow, an image slicer in the Forestry Dept. was investigated. Imagery for 22 and 23 February 1974 were subjected to preliminary analysis. Figure 9 is a color print of the image of February 6 (NASA ERTS E 1579-16275-401) as viewed through the slicer. A uniform density increment was used. A comparison of the colored areas to measured water contents suggests the following:

Color	Water Content Inches	Area Sq. Miles	% Area
Yellow	Less than 1"	340	2.5%
Green	1" to 1.5"	1330	9.7
Blue	1.5" to 2.0"	4460	32.6
White	More than 2"	7560	55.2
TOTAL		13,690	100.0

The area and percent area of each color were determined by the slicer. An interpretation of the water content of snow in each color-area was based on a comparison with field measurements. As some field data are available for comparison with the color image, there is a basis for an approximate relationship between color and water content as shown in the above table. The density of the original image negative (Fig. 6) is a function of both water content of snow and of the percent snow cover. There is a question as to the interpretation of some field measurements so as to reflect both factors. However, the color print from the image slicer is also of considerable value in drawing water content of snow lines. The lines of Fig. 8 were drawn without the aid of Fig. 9. It appears that further refinements could be made on the basis of Fig. 9 and the above table.

One of the primary objectives of this study is to develop a graphical relationship between "Per Cent Snow Cover" and "Water Content of Snow". Figure 10 shows the data obtained to date from field measurements, low-altitude aerial photographs and the ERTS Imagery. The results indicate very good agreement has been achieved on the form of this relationship for the

Upper Midwest. The curve should be a function of general topography and probably is different for mountainous regions than it is for the relatively low relief of the Upper Midwest.

CONCLUSIONS

1. ERTS Imagery has been very helpful in drawing water-content-of-snow lines just prior to the spring melt for 1973 and 1974. This should be very valuable in predicting the magnitude of spring floods if the imagery can be provided promptly to flood forecasters in the period February 1 to March 31 each year.
2. As part of the study, a graphical relationship has been developed between "Per Cent Snow Cover" and "Water Content of Snow" for the Upper Midwest. This relationship is necessary for the proper use of some modern mathematical simulation models used in flood forecasting.
3. It is difficult to estimate the value of the ERTS Imagery in this study but flood damage in the upper midwest has exceeded 300 million dollars in 1965 and 1969; anything that can be done to provide warning and prepare emergency countermeasures will make a significant contribution to the reduction of such damage. The ERTS Imagery has this capability.

FIGURE CAPTIONS

Fig. 1: Water content of snow in central Minnesota after use of Erts Imagery, 6 Feb 73.

Fig. 2: Computer printout of observed and computed discharge for the Le Sueur River in March and April, 1969.

Fig. 3: Computed and observed flood flows for the Le Sueur River for 1965 and 1969, with various water content of snow values as of March 1 of the respective year.

Fig. 4: Measured values of water content of snow in Southern Minnesota for 19 Feb 74. Underlined values were obtained by the author on 16 Feb as part of this project.

Fig. 5: Water content of snow lines for 19 Feb 74 in Southern Minnesota, drawn without the aid of Erts Imagery.

Fig. 6: Erts Image of 22 Feb 1974 (Band 4) showing snow cover in Central Minnesota. The Mississippi River is the diagonal line from upper left to right central. Mankato is in the dark area near lower left corner, an area of relatively light snow cover. This does not support data for ground measurements in this area. The image is of considerable value in drawing water content lines.

Fig. 7: Erts Image of 23 Feb 74 (Band 4) showing snow cover in South Central Minnesota. The Minnesota River is the dark line across the central part of the image. Mankato is in the dark area near lower right corner.

Fig. 8: Water content of snow lines for 19 Feb 74 in Southern Minnesota,

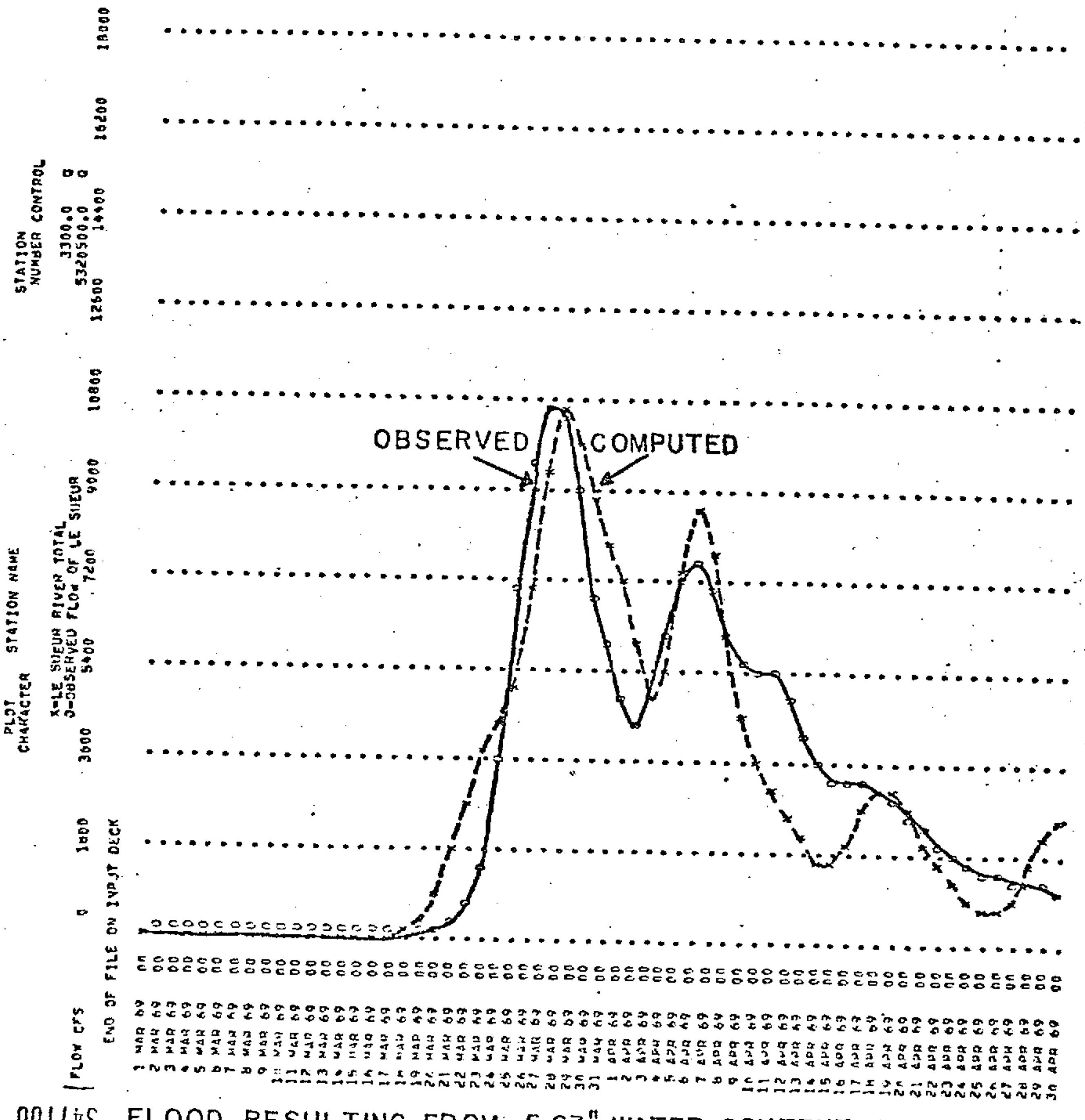
drawn with the assistance of Erts Imagery (Figs. 6 and 7).

Fig. 9: South Central Minnesota (NASA ERTS 1579-16275-401; Band 4) reproduced with the aid of an image slicer. The Twin Cities of Minneapolis and St. Paul are in the yellow and green area in the upper center of the photo. The white areas generally have a water content of snow of 2 inches or more.

Fig. 10: Percent snow cover as a function of water content of snow.

6 FEB 73

Fig. 1



FLOOD RESULTING FROM 5.63" WATER CONTENT OF SNOW

Fig. 2

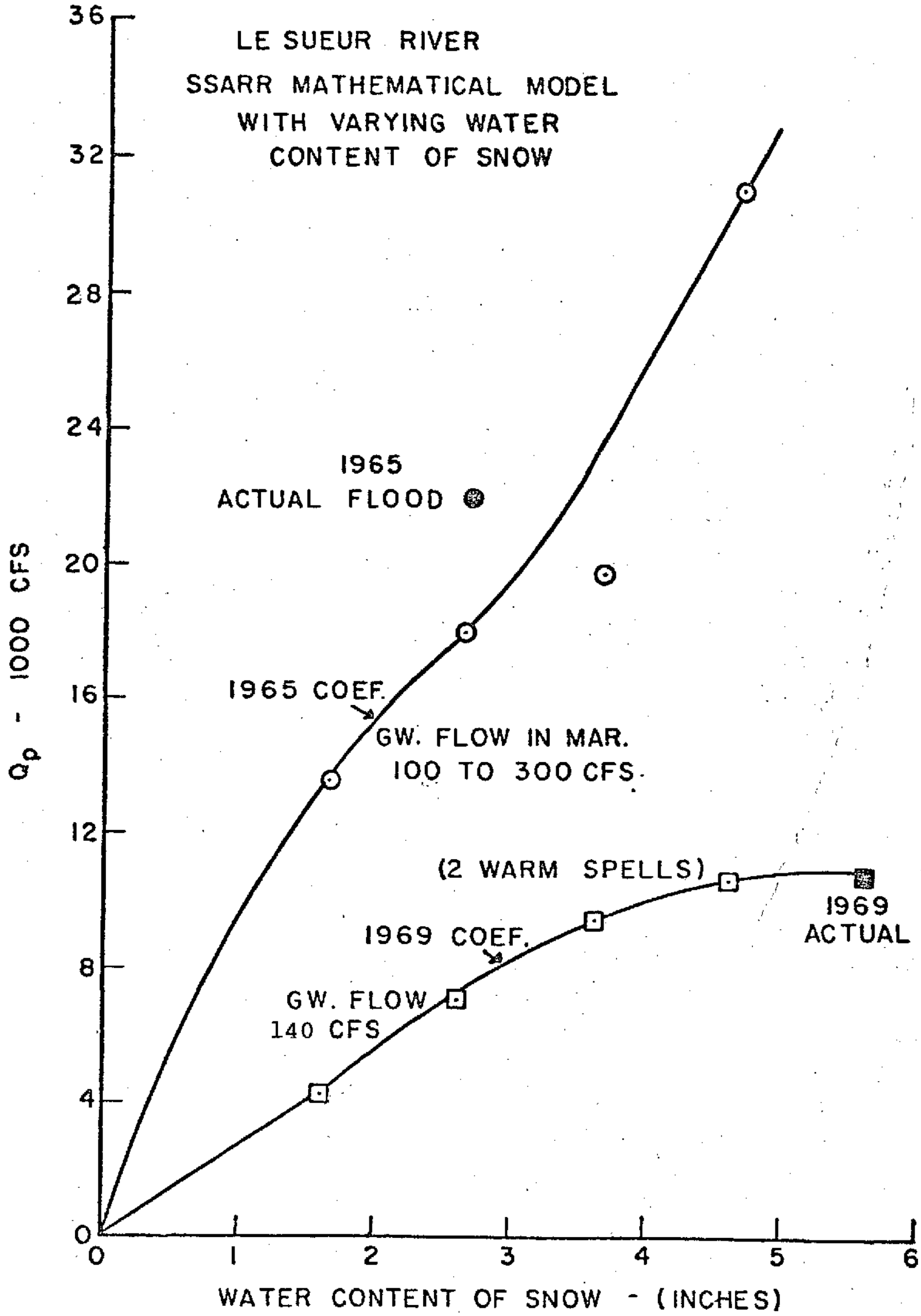

LE SUEUR RIVER
SSARR MATHEMATICAL MODEL
WITH VARYING WATER
CONTENT OF SNOW
1965
ACTUAL FLOOD
1965 COEF.
GW. FLOW IN MAR.
100 TO 300 CFS
(2 WARM SPELLS)
1969
ACTUAL
1969 COEF.
GW. FLOW
140 CFS
Q_p - 1000 CFS
WATER CONTENT OF SNOW - (INCHES)
0
4
8
12
16
20
24
28
32
36
0
1
2
3
4
5
6

Fig. 3

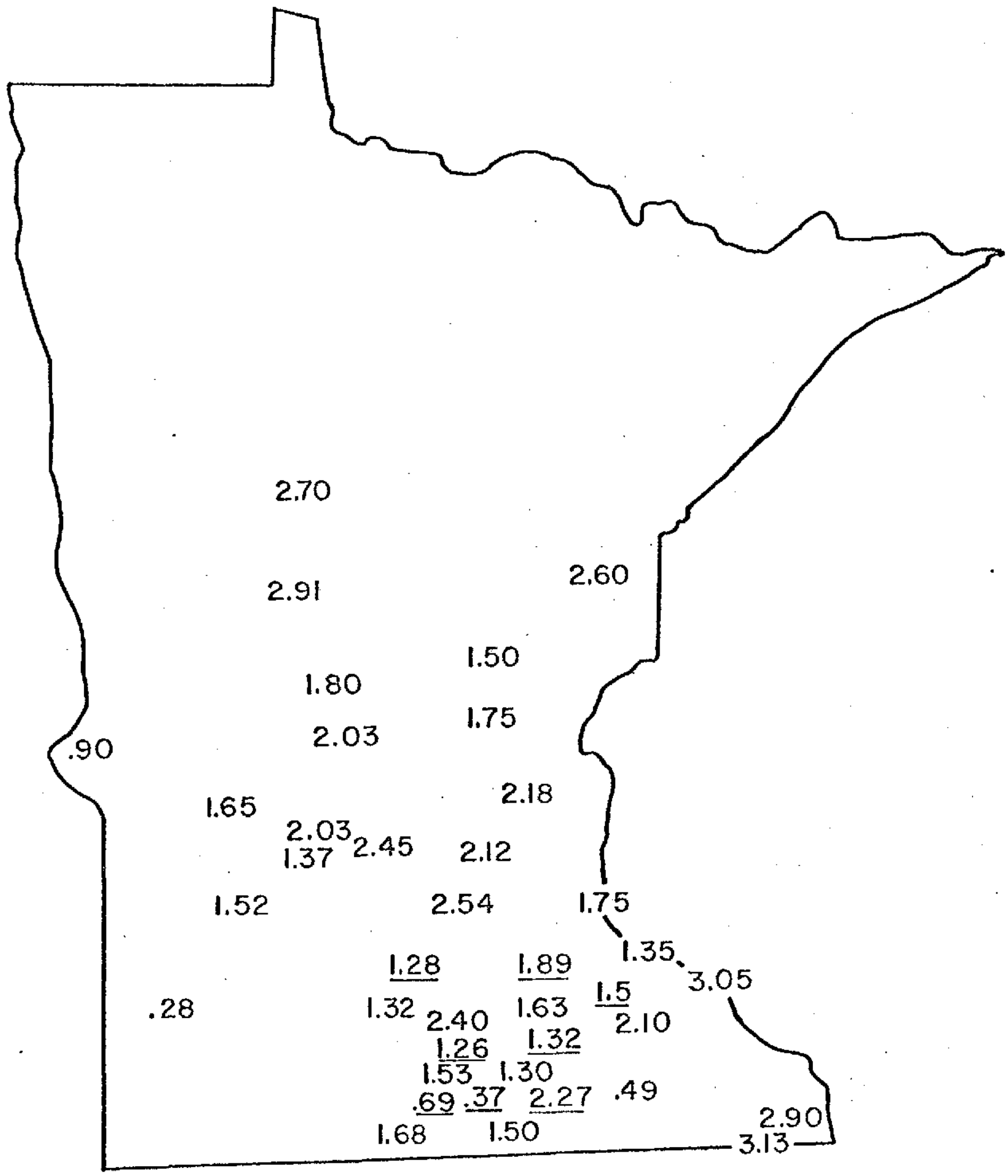
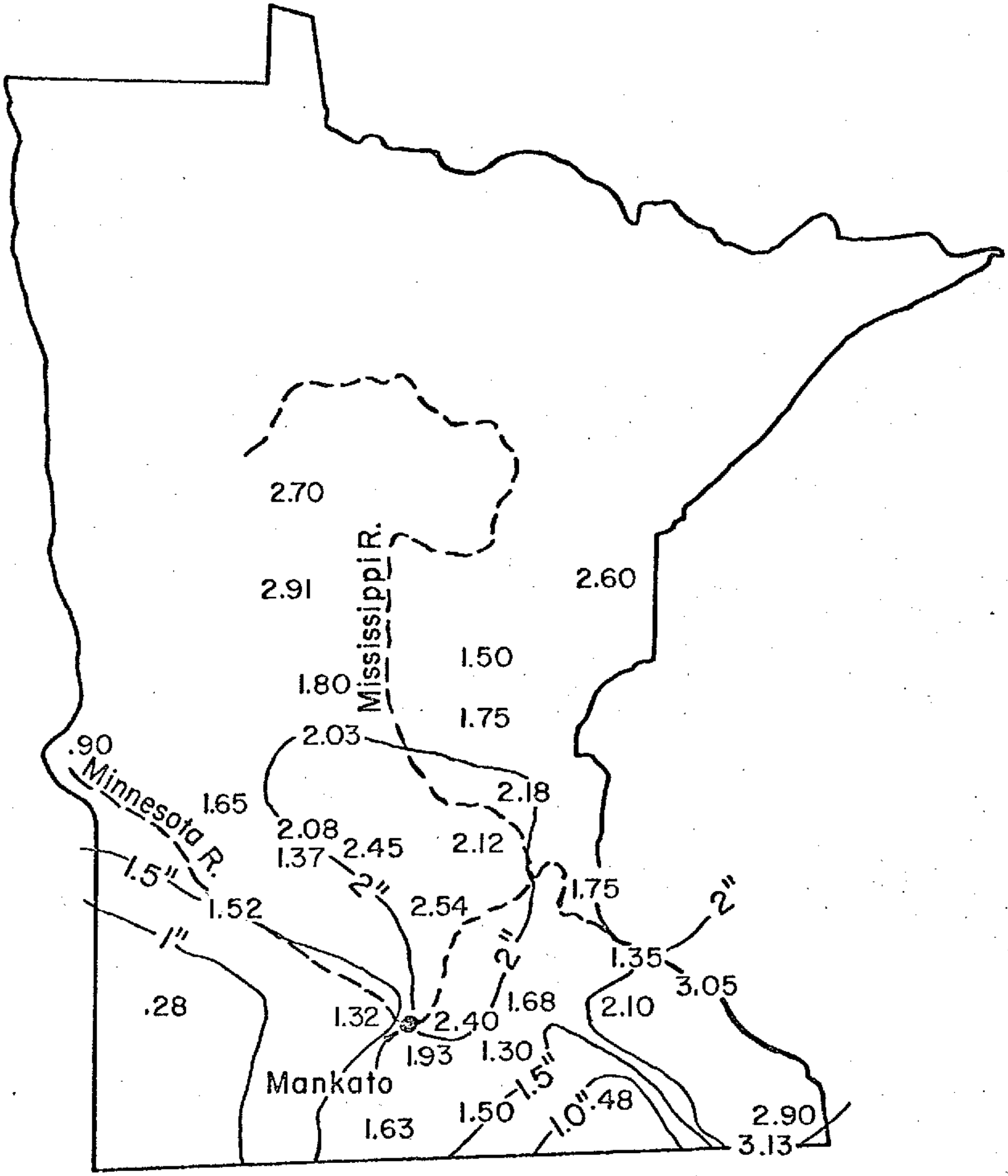

2.70
2.91
2.60
1.50
1.80
1.75
2.03
.90
2.18
1.65
2.03
1.37
2.45
2.12
1.52
2.54
1.75
1.35
3.05
1.28
1.89
1.5
.28
1.32
2.40
1.63
2.10
1.26
1.32
1.53
1.30
.69
.37
2.27
.49
2.90
1.68
1.50
3.13

Fig. 4



2.70
2.91
Mississippi R.
2.60
1.50
1.80
1.75
2.03
.90
Minnesota R.
1.65
2.18
2.08
1.37
2.45
2.12
1.5"
2"
1.75
2"
1.52
2.54
1"
2"
1.35
3.05
.28
1.68
2.10
1.32
2.40
1.93
1.30
Mankato
1.5"
1.0"
.48
1.63
1.50
2.90
3.13

Fig. 5

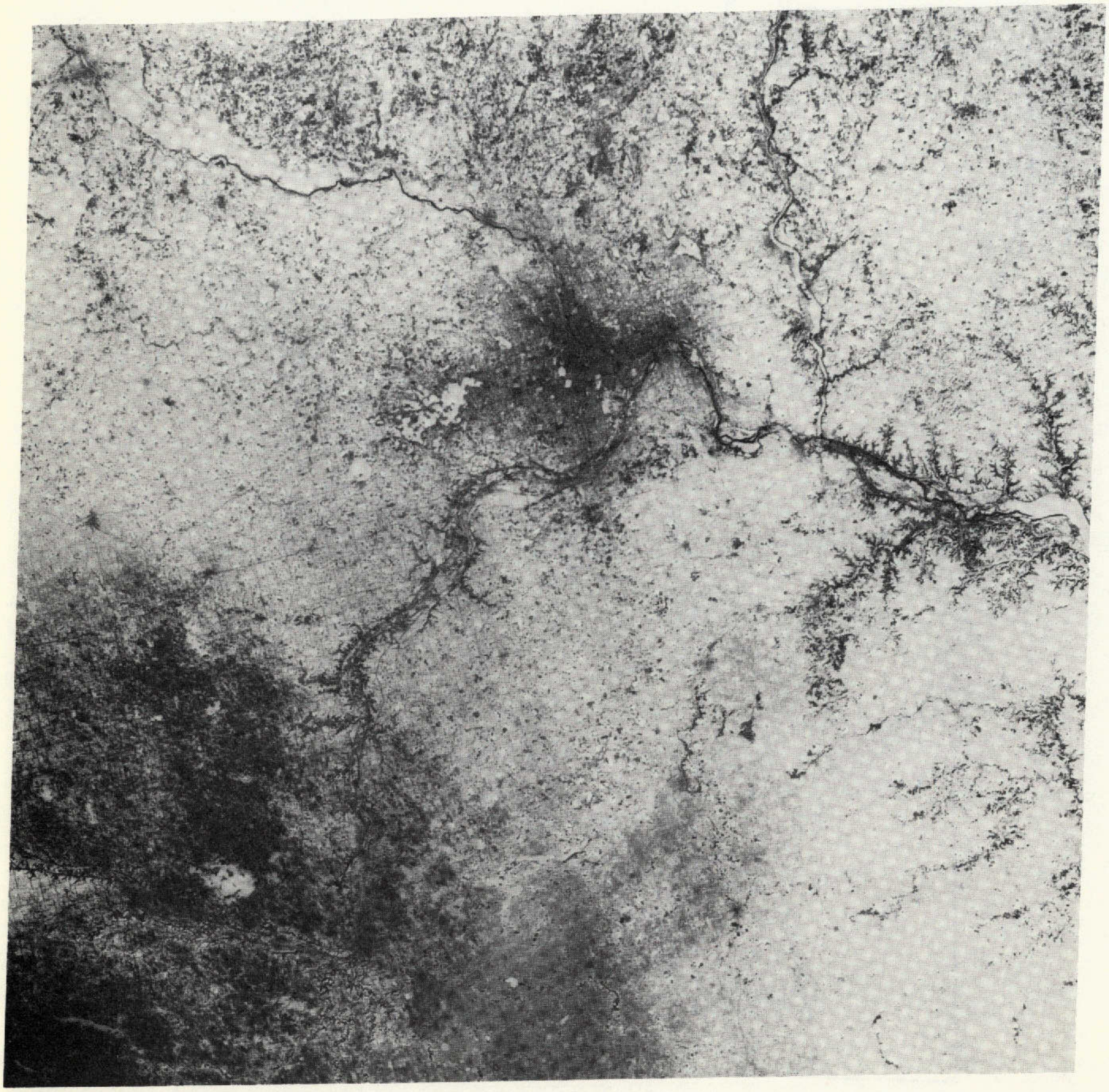


Fig. 6

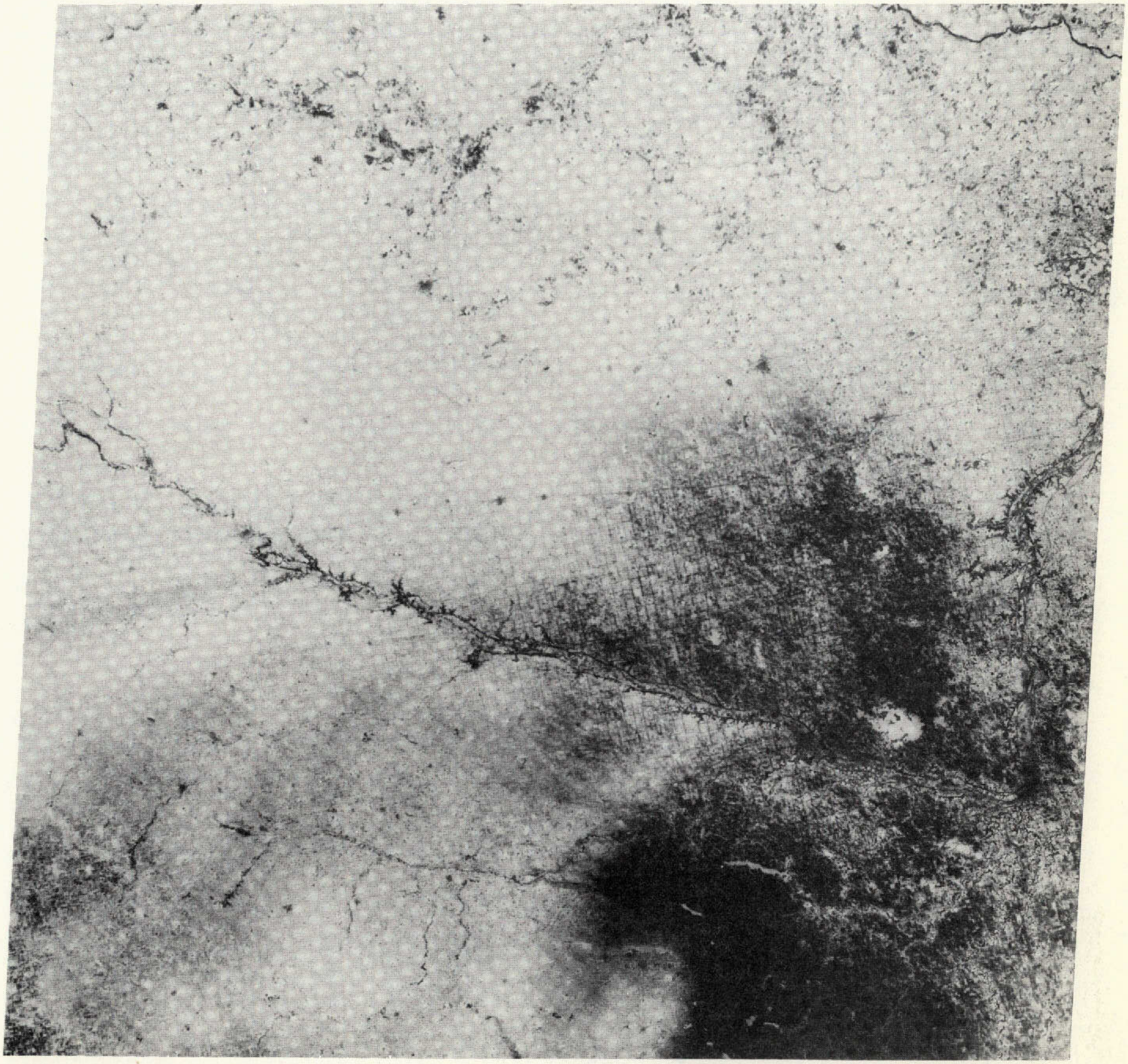


Fig. 7

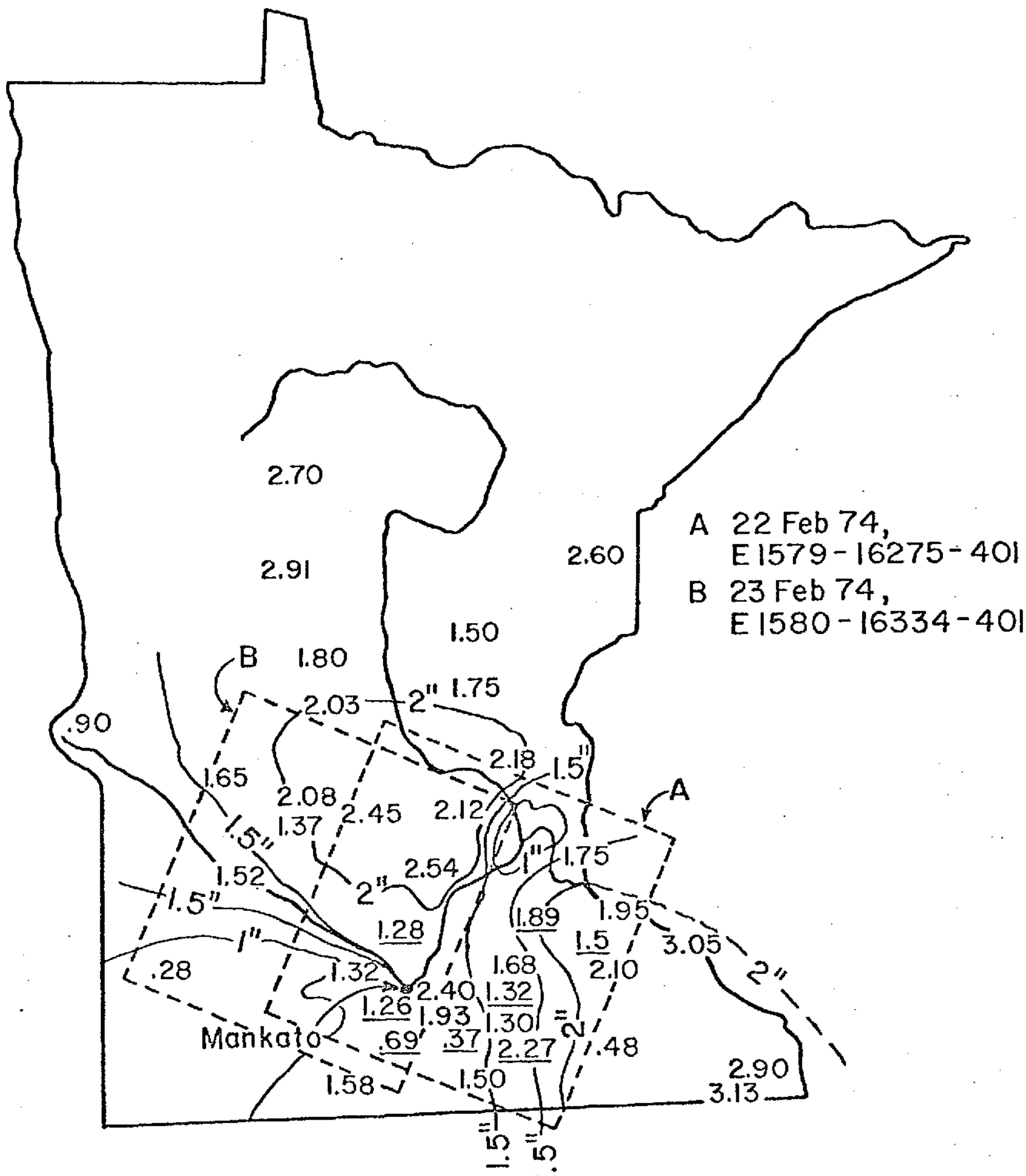
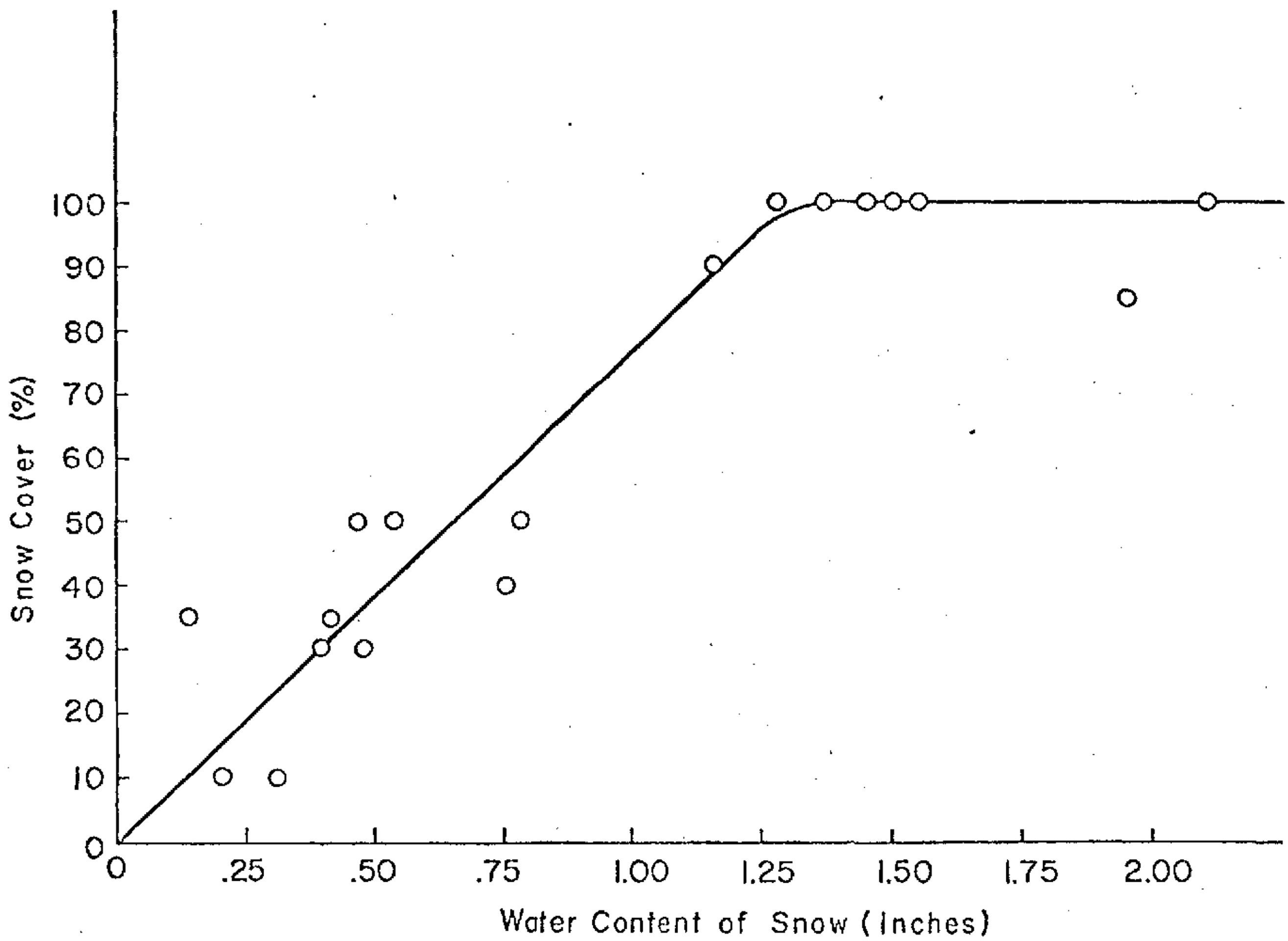

A 22 Feb 74,
E1579-16275-401
B 23 Feb 74,
E1580-16334-401
A
B
2.70
2.91
2.60
1.50
1.80
1.75
2.03
2"
.90
2.18
1.5"
1.65
2.08
2.45
2.12
1.37
1.5"
1.75
2.54
1"
1.52
2"
1.5"
1.28
1.89
1.95
1"
1.5
3.05
2"
.28
1.32
1.68
2.10
2.40
1.32
1.26
1.93
1.30
2"
Mankato
.69
.37
2.27
.48
2.90
1.58
1.50
3.13
1.5"
1.5"

Fig. 8

22 FEB 74

Fig. 9



100
90
80
70
60
50
40
30
20
10
0
Snow Cover (%)
0
.25
.50
.75
1.00
1.25
1.50
1.75
2.00
Water Content of Snow (Inches)

Fig. 10

REMOTE SENSING APPLICATIONS TO HYDROLOGY IN MINNESOTA

Investigators: Dr. Dwight Brown and Dr. Richard Skaggs
Department of Geography
University of Minnesota, Minneapolis

Introduction

The past two years efforts have been directed toward the application of satellite and high altitude photographic imagery to a variety of hydrologic problems. The studies include:

1) The investigation of surface cover data to develop surface runoff coefficients for noninstrumented watersheds. These are described in the appended Rice Creek Watershed Project final report.

2) The detection of surface water and seasonal surface water changes with ERTS imagery. This work is reported in the appended technical report (and MA thesis) by Steven Prestin and has provided the basis for a cooperative project involving several state agencies and the university. This project is aimed at mapping open surface water overlays for 1:24,000 topographic maps for the state and will be described later.

3) The application of ERTS-1 MSS imagery to the detection of Peaty Wetlands. This study has not been carried beyond the stage reported in the December 31, 1973 report.

4) The application of high altitude aerial photography and manually interpreted and density sliced ERTS-1 images to the development of an urban hydrologic model for the Twin Cities Metropolitan Area. This work will be described in more detail in this report.

5) The investigation of multi-seasonal ERTS-1 imagery for classification of lake quality in Minnesota. This is a cooperative project between the Geography Department and the Limnological Research Center at the University of Minnesota. This work is just beginning and will be described in this report.

Following the description of above projects we will summarize the benefits, describe equipment usage, and informational meetings held during the past fiscal year.

Inventory and Seasonal Change of Open Water in Minnesota

The capabilities of using multi-seasonal ERTS-1 imagery for inventory and change detection of open water, as demonstrated in the appended technical report by Steven Prestin (Appendix II), encouraged the development of a cooperative project to update Minnesota surface water information. Prestin shows that ERTS-1 images can be used to detect and map water bodies greater than 10 acres. Mapping accuracy declines for lakes between 5 and 10 acres and is unsatisfactory below 5 acres. The ERTS-1 imagery is currently the only nearly synoptic and contemporary source of information on Minnesota lakes. These attributes make it potentially a much more valuable tool than the U.S.G.S. topographic maps, county highway maps, or Minnesota Department of Natural Resources (MDNR) "Inventory of Minnesota Lakes," Bulletin No. 25. Furthermore the cost differences between ERTS imagery and conventional methods of updating the inventory weigh very heavily towards use of ERTS-1 imagery.

Prestin also shows that intra- and inter-annual fluctuations of open water can be detected using the repetitive ERTS coverage. Subsequent activities have been built on this aspect of Prestin's work.

Encouraged by the demonstrated ability to map seasonal change in open water, a series of meetings discussing the hydrologic applications of ERTS imagery with technical as well as administrative heads of each division in MDNR and various personnel from the Minnesota State Planning Agency (MSPA), the Minnesota Land Management Information System (MLMIS), the University of Minnesota Water Resources Center (WRRC), the University of Minnesota Center for Urban and Regional Affairs (CURA), the University of Minnesota Limnological Research Center (LRC), the University of Minnesota Space Sciences Center (SSC), and the University of Minnesota Department of Geography. These meetings have yielded an elaboration of surface water information needs, of the most useful data format, and of work priorities.

Lake Information Needs and Format

The basic information need is a current inventory of surface water. "The Minnesota Lake Inventory," D.N.R. Bulletin No. 25, is the most recent publication on this particular topic and the best source of information on lake basins. However, it is based on data ranging in age from 10 to 38 years and required about 11 years to complete. The legislature recently required that the Minnesota Department of Natural Resources (MDNR) identify public waters by January 1, 1975. It became obvious that other methods should be attempted to verify and update lake information for the state so that public waters could be identified according to recent legislative definitions. From the meeting it was concluded that the most useful scale for lake mapping would be 1:24,000, that all detectable water should be mapped, and that seasonal change in open water should be included if possible. To test ERTS-1 imagery at this scale, a test project was set up in Ramsey County. Ramsey County was selected to maximize available information on open water and to allow the use of recent NASA high-altitude photographs.

Procedure

At the first mapping attempt, several problems were discovered. In order to determine maximum and minimum open water, different seasonal images representing the two extremes had to be used. It readily became apparent that it was more useful to verify the extent of open water on existing topographic maps rather than mapping directly from ERTS-1 imagery alone. This decision arose from the problems of geometry and registrations and the need to use topographic information to refine the strand line locations. (See overlapping of seasonal images with topographic map on Figure 1.)

The following steps summarize the procedure of using ERTS-1 imagery to produce a more useful product:

(1) Project ERTS image to fit 1:24,000 scale.*

(2) Trace lakes from different seasonal images.

(3) Select appropriate dates of extreme changes.**

(4) Trace extreme extent of open water from ERTS changes and topographical map shapes.

(5) Verify lake boundaries information with topographic information.

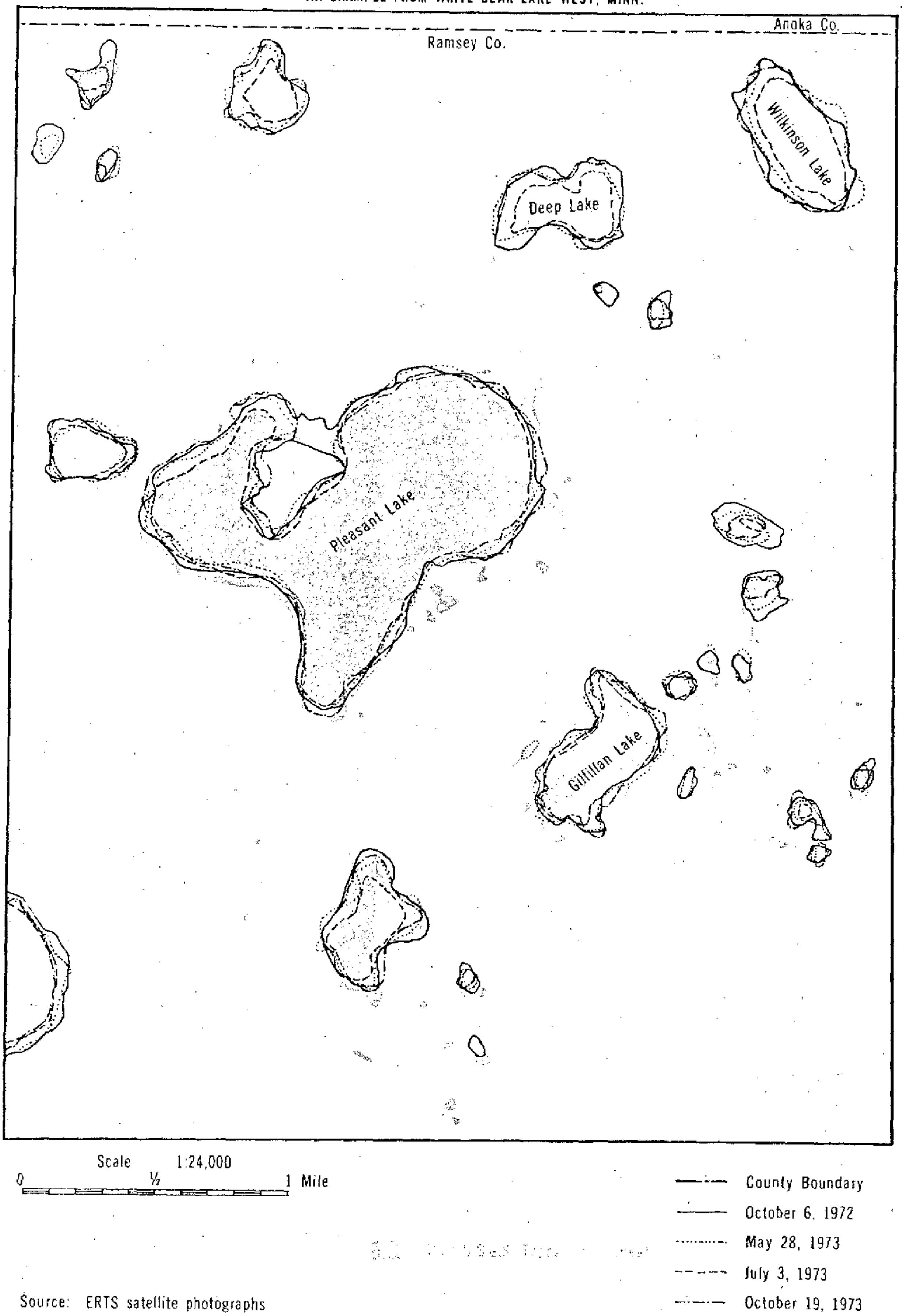
Figures 2 and 3 show reduced versions of this product for 1:24,000 two quadrangles within Ramsey County.

* Using close-up slides of ERTS-1 color combined 9 1/2" transparencies centered on the quadrangle.

** Includes definitions about detectable or undetectable lakes with consideratio of cartographic technique.

MAPPING LAKES FROM FOUR DATES OF ERTS IMAGERY

AN EXAMPLE FROM WHITE BEAR LAKE WEST, MINN.



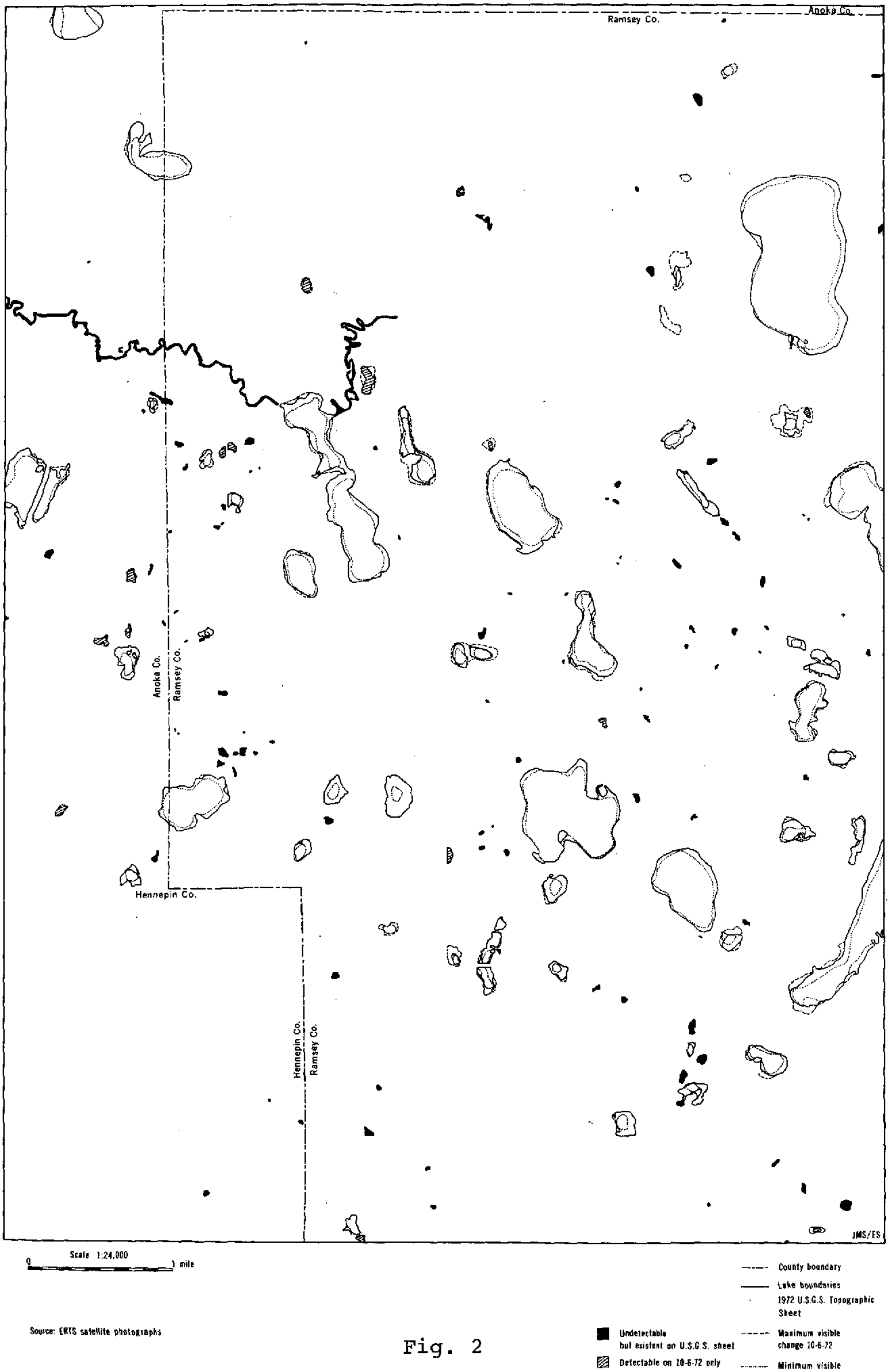
Source: ERTS satellite photographs

FIGURE 1

John M. Smiley & Eliahu Stern
Geography Department/University of Minnesota

NEW BRIGHTON QUADRANGLE, MINN.

VISIBLE LAKE CHANGES

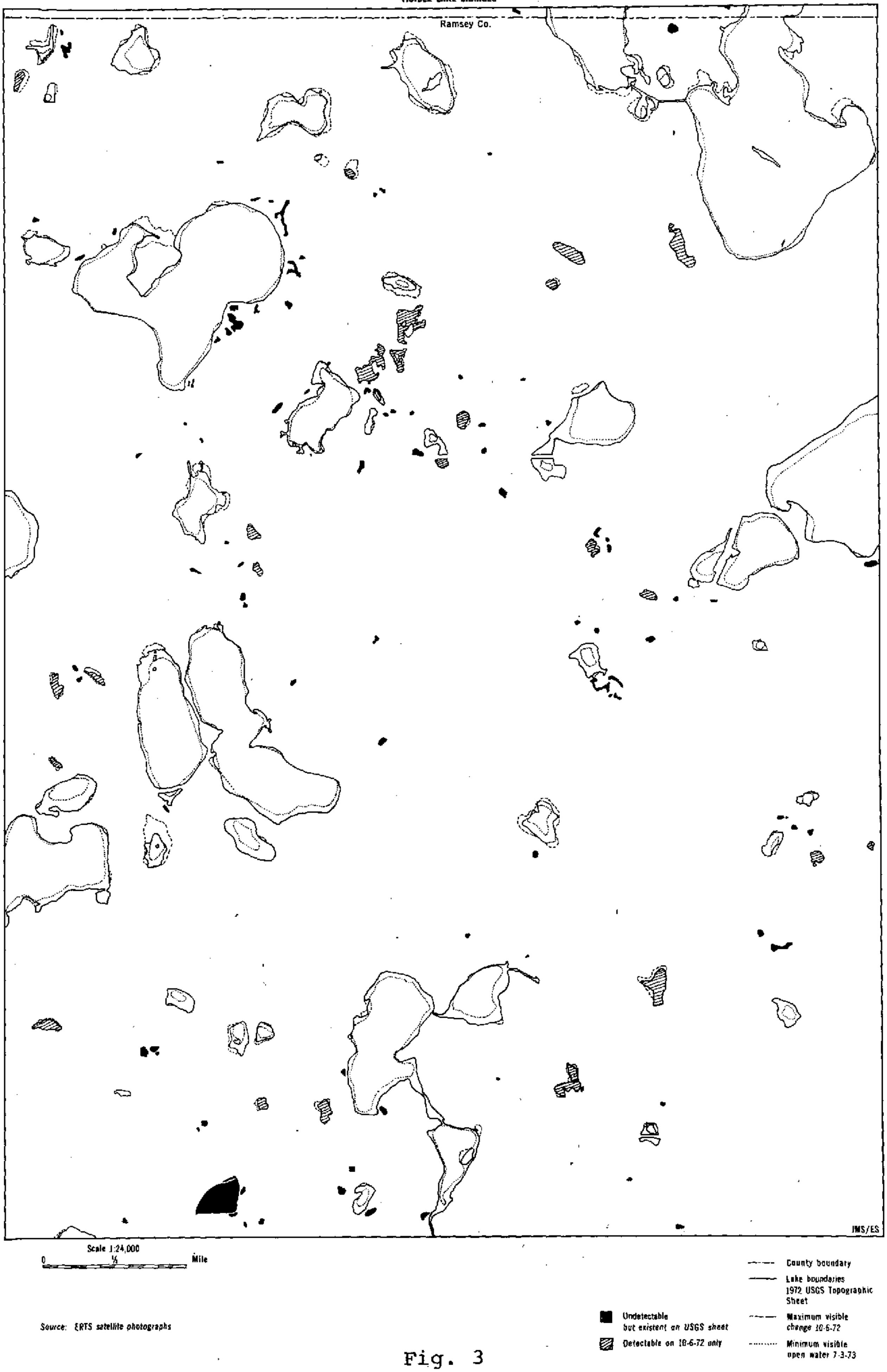


Source: ERTS satellite photographs

Fig. 2

WHITE BEAR LAKE WEST, MINN.

VISIBLE LAKE CHANGES



Source: ERTS satellite photographs

Fig. 3

Work Priorities

MDNR has established two priority areas and a cooperative pilot project involving two state agencies and the University which began to map the copper-nickel study area in Northeastern Minnesota on July 1, 1974. The potential issuance of mining permits in this area necessitates a definition of the hydrologic systems subject to environmental impact. These systems and their dynamics are not now known. The second area is the Twin Cities Metropolitan Area. The procedures developed under this project form the basis of the cooperative project. It is expected that this project will be expanded to include selected high priority areas if not the entire state in the coming year. The maps being produced are designed for input into both the Minnesota Land Management Information System and a water information system.

The total labor for producing one quadrangle in the Ramsey County test area was approximately eleven person hours work. This includes all work from the slide photocopying of the quadrangle area from 9 1/2" ERTS-1 color transparencies for two seasons to the completion of the final cartographic product. Material costs are about $3.00 per quadrangle. The labor will be reduced for the copper-nickel and the Twin Cities test areas by more than 20% because of the efficiencies of a larger scale operation.

Reconnaisance Analysis of Lake Quality in Minnesota with ERTS-1 Imagery

Little water quality information is presently available on the approximately 15,000 lakes in Minnesota. Dr. Shapiro, Associate Director of the Limnological Research Center (LRC), is directing a program for collecting water transparency data for a large number of Minnesota's lakes. This survey depends on cooperative citizens who provide weekly information on specific lakes. Citizen support is good but, at the most optimistic level, would only provide information on 5 - 7% of the lakes in the state.

Very preliminary analysis using raw, uncorrected lake reflection values from ERTS-1 images for 16 lakes indicates a strong inverse relationship between bands 4, 5, and 6 and water transparency readings. These findings encouraged us to investigate the relationship between ERTS-1 images and water transparency data for the summer of 1973 in order to evaluate the degree to which existing water quality information can be extended with the aid of satellite images.

Within a month we expect to have the analysis of the 1973 imagery complete and will be able to use our findings to collect additional water quality data at times of satellite overpass. The ultimate goal of the Geography Department-Limnological Research Center project is to identify and classify lakes of different quality in the state so that the more expensive ground investigations can be directed toward lakes where remedial action or conservation measures are deemed to be high priority.

An Urban Hydrologic Model for the Twin Cities Minnesota

As watersheds become more urbanized and damage due to flooding more severe, new methods of determining runoff are necessary. Since past flood records cannot be used to predict runoff from a changing watershed, rainfall-runoff methods must be employed. These involve such parameters as rainfall intensity and duration, basin shape and drainage network characteristics, soil infiltration capacities and land use. Studies have shown that most runoff volume results from impervious surfaces. However, the percentage of area that is impervious is often tediously determined from non-current information or estimated from gross land use categories. A better evaluation of this most important parameter would enable the prediction of runoff results that would be more accurate and more sensitive to urban developmental change.

This study is attempting to develop the methodology for deriving density of impervious surfaces from ERTS satellite imagery. Different season color ERTS provided for each of the three land use categories has yielded the most promising results when compared to impermeable surface density calculated from NASA high-altitude aerial photography for Ramsey County. Multiple correlation coefficients as high as .80 (R2 = 64) using this procedure. Completion is expected by February, 1975.

Equipment Usage

The image density slicing system, part of which was purchased under this contract along with that purchased by CURA and the Geography Department, as well as personal equipment of the principal investigators, has been used to support a variety of research. Professors Sydor and Bowers have used the equipment for their projects. It has been used in several phases of this project, for support of the CURA and S.P.A. cooperative remote sensing project and for support of a variety of classes and seminars dealing with remote sensing problems in the geography department.

Summary

Two projects have proceeded far enough for us to make estimates of the cost and time savings resulting from the use of Remote Sensing Technology. The Rice Creek Watershed land use map, produced from NASA high altitude aerial photography yielded a higher quality product and a cost savings of 3 person months over the ground mapping methods that were contemplated at the time the project was initiated. In addition it was demonstrated that such a product could be produced in less than two weeks with the aid of high altitude aerial photography. It's more difficult to compare savings in the case of open water mapping. The DNR Bulletin #25 required between 300 and 500 man months to complete. While this project stops short of an inventory, it does provide much more detail than is available in that report and in a format that is more useful to field personnel.

Based on Prestin's work we estimate the time for mapping lakes at a 1:125,000 scale to be under 3 work weeks for the entire state. Measurement of lake area greatly adds to the time necessary, but would bring the total mapping and measurement time to 9 man months.

Upon review of the current use problems of Bulletin #25, particularly by fish and wildlife and enforcement divisions, MDNR concluded that updating and validating maximum seasonal extent of open water on 1:24,000 topographic maps would be most valuable. These lakes could then be digitized and area measurements could be carried out when the state-wide water information system is completed. In addition, they desired information on seasonal change.

Project costs for a full state-wide project based on the Ramsey County Test Site are about 80 man months as opposed to the estimates for completion of Bulletin #25 that run in the neighborhood of about 350 man months. In addition at least two seasons of high altitude aerial photographic coverage would be necessary, conservatively at a cost of $400,000. Such coverage would be valuable to other agencies, but this project would undoubtedly have to bear a substantial portion or make serious compromises to accommodate a wider user community.

Appendix A

RICE CREEK WATERSHED PROJECT

John Harrington, Research Assistant

Joseph Gibson, Research Assistant

Richard Skaggs, Associate Professor

Dwight Brown, Associate Professor

Department of Geography

University of Minnesota, Minneapolis

Minneapolis, Minnesota 55455

Rice Creek Watershed Project

Early in 1973, we began cooperating with the Rice Creek Watershed District through the Board of Managers and their consulting engineering firm, Hickok and Associates. At the time we began the cooperative work, the Rice Creek Watershed District had recently been created and had little basic data on which to base their plans and regulatory land use decisions. The Districts have broad powers in maintaining water quality and in developing flood protection measures.

The first cooperative venture involved a pilot land use map of the Pike Lake sub-Watershed. The map and report have been forwarded previously. These data were necessary to define the 100 yr. flood zone with rainfall-runoff models in order to comply with the specifications of the federal flood insurance program. This project proved useful to the District, and we were asked to compile a land use map for the total watershed. That project was completed during the 1973-1974 fiscal year.

The land use for the entire watershed was mapped at a scale of 1:36,680. The interpretation was based on NASA high altitude infrared photographs. (see end of report for image details). The classes of land use types are an expanded version of classes used in the Pike Lake study. There are 15 discrete classes under the general headings of residential, commercial, industrial, open space, water bodies, and wetlands. (see map for details). These classes are the ones specified by the consulting engineers as necessary for input into their hydrologic model.

The interpretations of land use data from the NASA photography took about 72 man-hours. We estimate a savings of about 3 man-months over conventional ground mapping techniques. Furthermore, we believe that the locational and areal accuracy of the photo-interpreted land use data is greater than could be obtained from ground mapping techniques. The level of detail is, however, about the same in the two mapping techniques. Thus, the advantages demonstrated by this project are the greater speed, the greater accuracy, and the man power savings provided by the use of NASA high altitude, aerial photography.

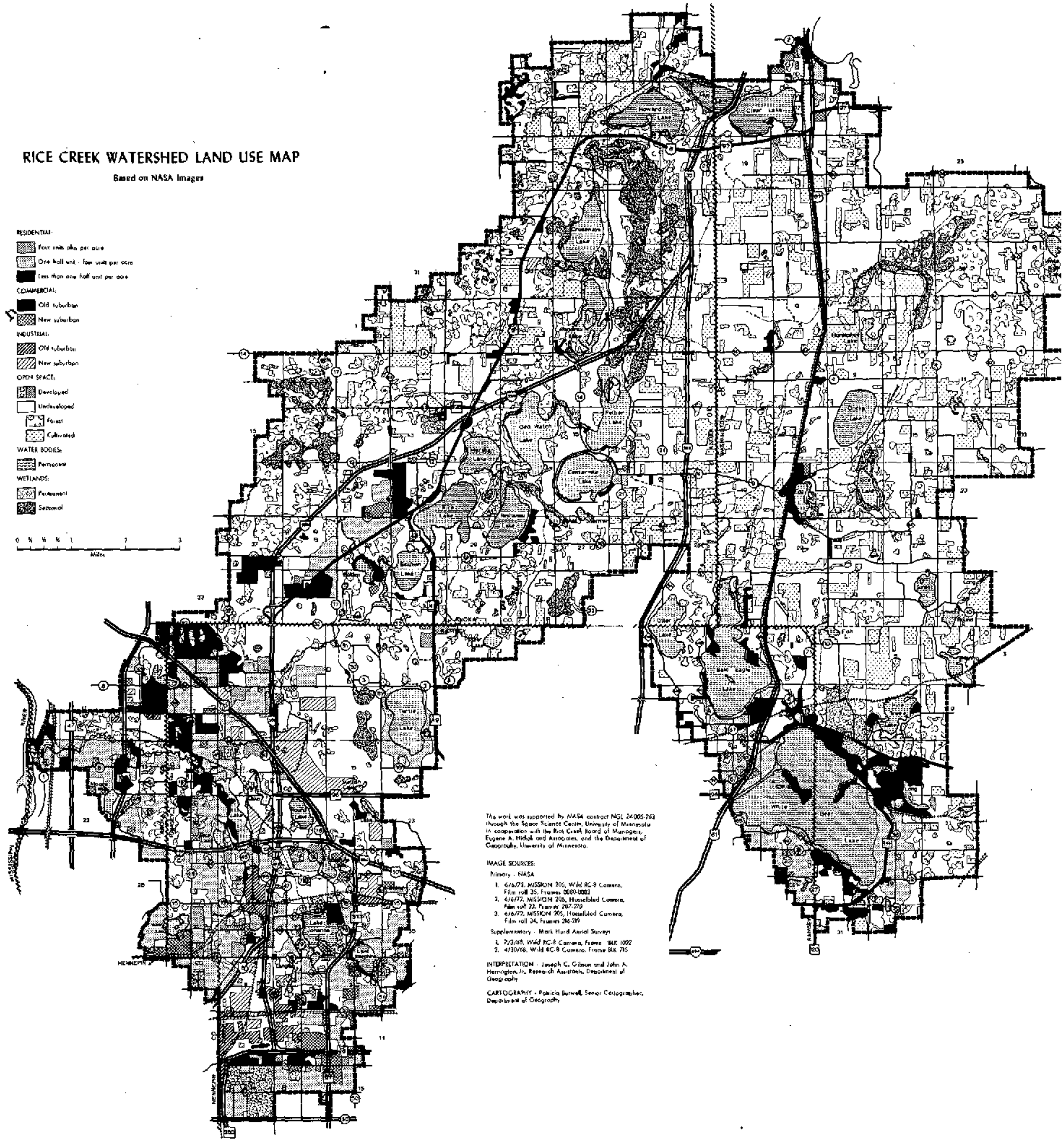
Other than the evaluation of time savings by employing aerial photography, the quality of the product can only be evaluated in terms of the outcomes of the hydrologic models for which the data were generated. These models yield a product that is dependent not only on the model design but also on all of the variables that are entered. Thus, is is nearly impossible to objectively assess the worth of the beyond its timeliness and cost of acquisition.

Images used:

Primary - NASA

1. 6/6/72, Mission 205, Wild RC-8 Camera, Roll 35, Frames 0080-0083.
2. 6/6/72, Mission 205, Hasselblad Camera, Roll 33, Frames 207-210.
3. 6/6/72, Mission 205, Hasselblad Camera, Roll 35, Frames 216-219.

-, 2


RICE CREEK WATERSHED LAND USE MAP
Based on NASA Images
RESIDENTIAL:
Four units plus per acre
One half unit - four units per acre
Less than one half unit per acre
COMMERCIAL:
Old suburban
New suburban
INDUSTRIAL:
Old suburban
New suburban
OPEN SPACE:
Developed
Undeveloped
Forest
Cultivated
WATER BODIES:
Permanent
WETLANDS:
Permanent
Seasonal
0 ¼ ½ ¾ 1 2 3
Miles
This work was supported by NASA contract NGL 24-005-263 through the Space Science Center, University of Minnesota in cooperation with the Rice Creek Board of Managers, Eugene A. Hickok and Associates, and the Department of Geography, University of Minnesota.
IMAGE SOURCES:
Primary - NASA
1. 6/6/72, MISSION 205, Wild RC-8 Camera, Film roll 35, Frames 0080-0083
2. 6/6/72, MISSION 205, Hasselblad Camera, Film roll 33, Frames 207-210
3. 6/6/72, MISSION 205, Hasselblad Camera, Film roll 34, Frames 216-219
Supplementary - Mark Hurd Aerial Surveys
1. 7/3/68, Wild RC-8 Camera, Frame BLK 1002
2. 4/30/68, Wild RC-8 Camera, Frame BLK 715
INTERPRETATION - Joseph C. Gibson and John A. Harrington, Jr., Research Assistants, Department of Geography
CARTOGRAPHY - Patricia Burwell, Senior Cartographer, Department of Geography
HENNEPIN

Appendix B

MANAGEMENT OF HYDROGRAPHIC FEATURES IN WEST-CENTRAL MINNESOTA FROM ERTS-1 IMAGERY

Steven J. Prestin, Research Assistant

Department of Geography
University of Minnesota, Minneapolis
Minneapolis, Minnesota 55455

ACKNOWLEDGMENTS

This study was partially funded by a grant, NGL24-005-263, from the National Aeronautics and Space Administration to the University of Minnesota's Space Science Center entitled "Remote Sensing Applications to Hydrology in Minnesota." Imagery and equipment, located in the Department of Geography at the University of Minnesota, was supplied under contract NAS5-21801 by the National Aeronautics and Space Administration to a cooperative research project entitled "Application of ERTS-I Imagery to State-Wide Land Information in Minnesota" involving the Minnesota State Planning Agency and the University of Minnesota's Center for Urban and Regional Affairs.

I would like to express my appreciation to my advisor, Professor Richard Skaggs, whose direction and encouragement made this study possible. I would also like to thank Professor Dwight Brown, director of the ERTS research effort in the Department of Geography, for his guidance during the course of this study. Additional thanks is due the several graduate students of the Department of Geography and personnel of the Minnesota Land Management Information System who provided both advice and encouragement. The fine cartography work was done by Patricia Burwell and Sandra Haas. Special thanks goes to Kristine Manlove for her helpful suggestions and diligent work in typing the final draft.

TABLE OF CONTENTS

TABLES

FIGURES

CHAPTER I. INTRODUCTION

Physical Setting - the Problem.

The thousands of lakes, marshes, and small ponds dotting the glaciated landscape of West-Central Minnesota offer an excellent example of a natural resource being dramatically altered by human action. Hydrographic changes in the area are end-products of conflicting land use pressures caused by a wide array of economic, social, and technological forces. Many wetlands have been drained to provide more agricultural land or to facilitate the use of increasingly sophisticated machinery and cultivation techniques. Others have been acquired (and often altered) by government agencies to enhance their recreation or aesthetic values. Many large lakes have been impounded to stabilize water levels and have had their shores altered by construction of seasonal homes. Chemical properties of surface waters have been altered by agricultural operations and sewage effluents. These man-induced alterations occur in conjunction with natural climatic forces which have created hydrographic fluctuations over several millennia.

An investigation of hydrographic fluctuations in West-Central Minnesota should provide insights that are applicable to conditions over a much larger area. The problem is essentially one of shallow marshes, ponds, and lakes in a prairie environment that exhibit pronounced annual and long term fluctuations in areal extent in response to quite variable climatic conditions. Leslie Hewes labeled the United States portion of this type of landscape the

"Northern Wet Prairie," and compiled a map based primarily on early soil survey reports (Fig. 1).[1] F.J. Marschner included a class of "Wet Prairie" on his map of original vegetation of Minnesota compiled from early land survey records.[2] These are both maps of conditions that pertained prior to extensive landscape alterations by humans. Since agricultural settlement, most of the southern and eastern protions of the Wet Prairie have been drained and put into agricultural uses. The portion that remains has been labeled the "Prairie Pothole Region" by the United States Department of Interior (Fig. 1).[3] The Pothole Region also encompasses large portions of the prairie provinces of Canada. A thorough economic analysis of the wetland drainage controversy was done by Jon Goldstein in which he concluded:[4]

> The allocation of wetlands between the agricultural and wildlife sectors has the classical characteristics of a resource distribution problem: one scarce resource with two alternative uses. The distribution of wetlands between the two sectors would be automatically and optimally determined by the operation of the market mechanism if the situation were purely competitive and free of the characteristics which cause market failures. But subsidies in the agricultural sector and the presence

---

[1]Leslie Hewes, "The Northern Wet Prairie of the United States: Nature, Sources of Information and Extent," Annals, Association of American Geographers, Vol. 41 (1951), p. 314.

[2]F.J. Marschner, Original Forests of Minnesota, (Map), (Washington, D.C.: U.S. Department of Agriculture, 1930). The original map has been lost, but two copies are on file at the North Central Forest Experiment Station, St. Paul, Minnesota.

[3]Grady E. Mann, "Improved Techniques for Aerial Wetland Surveys," Journal of Wildlife Management, Vol. 28 (1964), p. 576.

[4]Jon Goldstein, Competition for Wetlands in the Midwest: An Economic Analysis (Washington, D.C.: Resources for the Future, 1971), p. 1.

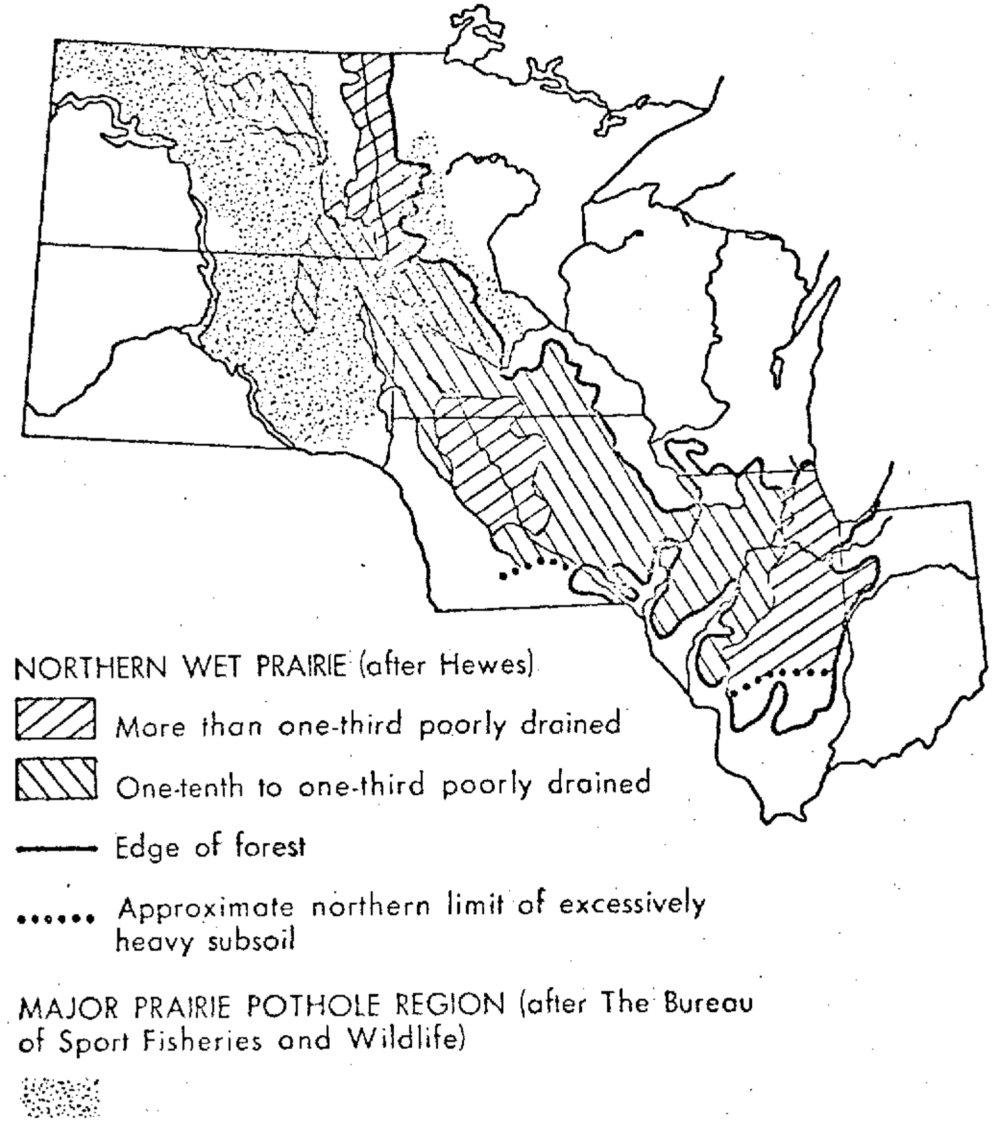


Fig. 1. Northern Wet Prairie and Prairie Pothole Region.

> of externalities and public goods properties prevent the market from functioning properly. The extent of drainage in the Upper Midwest during the postwar period together with crop surpluses has raised questions as to the social advisability of allowing the continued conversion of wetlands into arable land.

Robert Moline, a geographer, is the author of what must be considered the most comprehensive study of human alteration of the Wet Prairie.[5] He concentrates on the impact of European settlement on the natural landscape in the Minnesota River Drainage Basin above Mankato. Emphasis is on drainage of the Wet Prairie for agricultural expansion. In addition to citing early accounts of natural conditions, Moline examines the history of drainage in the United States, development of drainage techniques, diffusion of drainage technology, legal and corporate drainage systems, costs of drainage and sources of financing, and changing attitudes toward wetlands.

Prairie hydrographic features have a distinctive origin and morphology which permits several descriptive statements to be made about them. A recent study of potholes conducted by several investigators at the University of Minnesota Agriculture Experiment Station concluded that, although accumulations of organic deposits may help to seal lake bottoms, the initial deposits tend to be sand, silt, and clay which provide the original low permeability conditions necessary for surface water accumulation. They give

---

[5]Robert T. Moline, "The Modification of Wet Prairie in Southern Minnesota," unpublished doctoral dissertation, University of Minnesota, 1969.

the following account of the history of shallow lakes from immediate post-glaciation to the present:[6]

> We can safely infer that in such areas as soon as the depression developed, and before vegetation became established, wash of clay, silt, and sand into the depression was pronounced. The pond or lake acted as a settling basin and deposits of fine-grained relatively impervious material covered the bottom. When a vegetation cover was established, erosion of the adjacent land was probably minimized. The situation presumably continued until settlers entered the area. As soon as an area was settled and the forest or prairie grass was removed by cultivation, sheet wash and gully erosion started again. In some potholes a deposit of mechanical sediment was found over organic sediments which in many situations had been deposited during the long period of forest or prairie grass cover.

Potholes and prairie lakes have other distinguishing characteristics in addition to similar origins as basins formed by melting of remnant ice blocks or moraine deposition during glacial retreat. They are generally less than ten feet deep and have extensive areas of emergent vegetation in fertile waters making them high producers of waterfowl, shore birds, and aquatic fur bearers. In recent years many lakes have developed high populations of rough fish, whose destruction of aquatic vegetation has somewhat reduced valuable waterfowl habitat. Winterkills of fish caused by depletion of dissolved oxygen are common. An early study of four prairie lakes during the drought of the 1930's found that because of generally thorough mixing and high

---

[6]P.W. Manson, G.M. Schwartz, and E.R. Allred, Some Aspects of the Hydrology of Ponds and Small Lakes, Technical Bulletin No. 257 (St. Paul: University of Minnesota Agriculture Experiment Station, 1968), p. 7.

turbulence, waters usually lack chemical and thermal stratification when ice-free.[7]

In conjunction with the soil and topographic conditions mentioned above, climatic variables combine to produce distinctive annual water balance regimens. An exhaustive study of about forty water bodies for the period 1963 through 1965 produced the following conclusions:[8]

> From December 1 to about April 1 there normally is an ice cover and the water and ice level in the majority of bodies is notably stable. Data from forty-seven small water bodies indicate the average seepage loss per day is 0.0032 foot or for a year is 1.17 feet.
> With the spring thaws, breakup of ice, and the usual frequent rains the water level rises; this rise may be slight or very pronounced, depending on the season. The crest of the rise may occur from mid-May to mid-June.
> With the advent of warmer weather and higher evaporation, the levels tend to decline in late summer. From September until freeze-up the decline in level becomes more gentle and after the freeze-up is small or even nonexistent. It is evident from available data that the main controlling factor of the level of water in small, shallow lakes and ponds is the relation between precipitation and evaporation.

A graphic display of the water balance situation responsible for the conditions described above is portrayed in an example from the Big Stone Lake Watershed investigation of the United States Geological Survey (Fig. 2).[9] The water balance diagram, which assumes an average soil moisture holding capacity of four inches,

---

[7]John N. Wilson, "The Limnology of Certain Prairie Lakes in Minnesota," The American Midland Naturalist, Vol. 59 (1958), p. 435.

[8]Manson, et. al., op. cit., footnote 6, p. 5.

[9]R. D. Cotter, L. E. Bidwell, E. L. Oakes, and G. H. Hollenstein, Water Resources of the Big Stone Lake Watershed, Hydrologic Investigation Atlas HA-213 (Washington, D. C.: U. S. Government Printing Office, 1966).

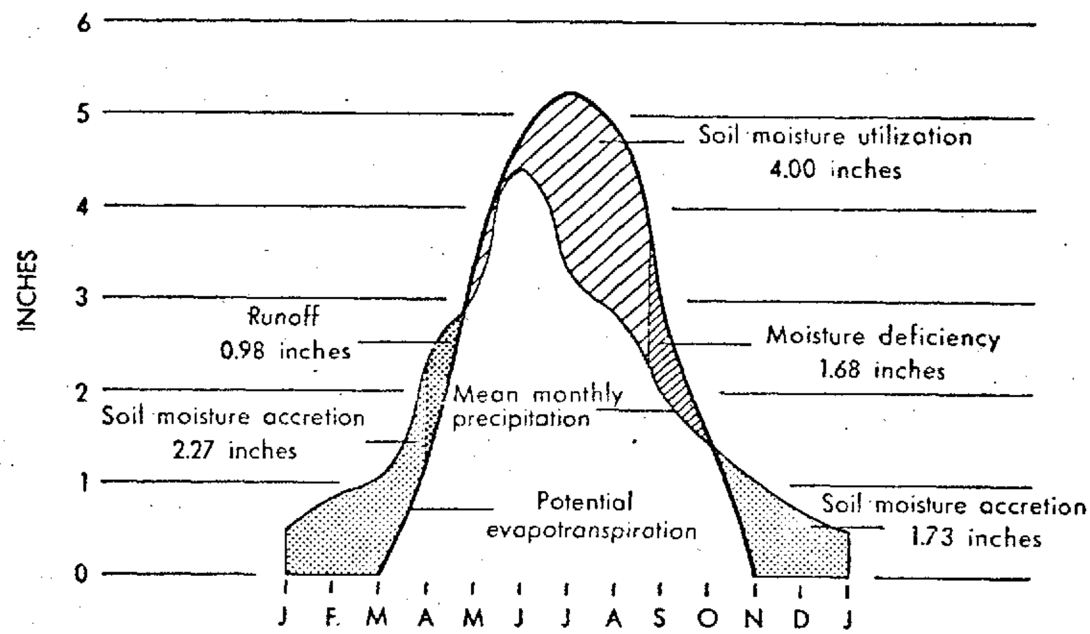


Fig. 2. Water balance regimen of the Big Stone Lake Watershed for 1945-62 (after Thornthwaite, 1948).

demonstrates that early spring is a period of excess water. This water becomes runoff which contributes to spring floods on streams and expansion of surface area of standing water bodies. In mid-summer potential evapotranspiration exceeds precipitation, causing depletion of accumulated soil moisture and contraction of surface water bodies.

The foregoing discussion has attempted to provide a basic understanding of the physical setting of shallow lakes, potholes, and wetlands of West-Central Minnesota. It has also sketched how this area fits into a larger regional setting and outlined some of the conflicts that have arisen as a result of settlement of the landscape by Europeans. The focus of this paper will be to evaluate how new developments in the field of remote sensing can help provide insights into the dynamics of the natural resource, assist present management efforts, and perhaps provide suggestions for new management procedures. Emphasis will be on recent satellite imagery, but some aircraft images will be used as collaborative evidence.

ERTS-I System: A Tool.

On July 23, 1972, the National Aeronautics and Space Administration (NASA) launched the first Earth Resources Technology Satellite (ERTS-I). The effort was designed as a "merger of space and remote sensing technologies into an R&D system for developing and demonstrating the techniques for efficient management of earth's resources."[10] This section will describe the ERTS-I system, giving particular emphasis to those features which are important for a clear understanding of the study.

ERTS-I was placed in a circular, sun synchronous, near-polar orbit at an altitude of 570 miles. It makes fourteen orbits per day, each taking about 103 minutes. The craft repeats orbits every eighteen days at the same time. In West-Central Minnesota, it passes at about 10:45 A.M. (C.S.T.). At this latitude successive orbits give about forty percent sidelap of flight lines on successive days. Seven orbits give complete coverage of Minnesota (Fig. 3).

The ERTS-I craft is equipped with three systems for monitoring earth. A Data Collection System receives information from automatic data collection platforms located in remote or inaccessible areas on the ground. The satellite performs as a communications link to relay this information to various data collection centers and provides investigators with measurements such as temperature, soil moisture, and snow depth that are less than twenty-four hours old. A second system consists of three Return Beam Vidicon Cameras which each sense a portion of the visible to near-infrared parts of the spectrum. This system malfunctioned after a short period of operation and will not be described further here. The third system is a Multi Spectral Scanner (MSS) which provided the images used in this study.

---

[10]Background information about the ERTS-I system in this section was obtained from the Data Users Handbook (Greenbelt, Maryland: National Aeronautics and Space Administration, 1972).

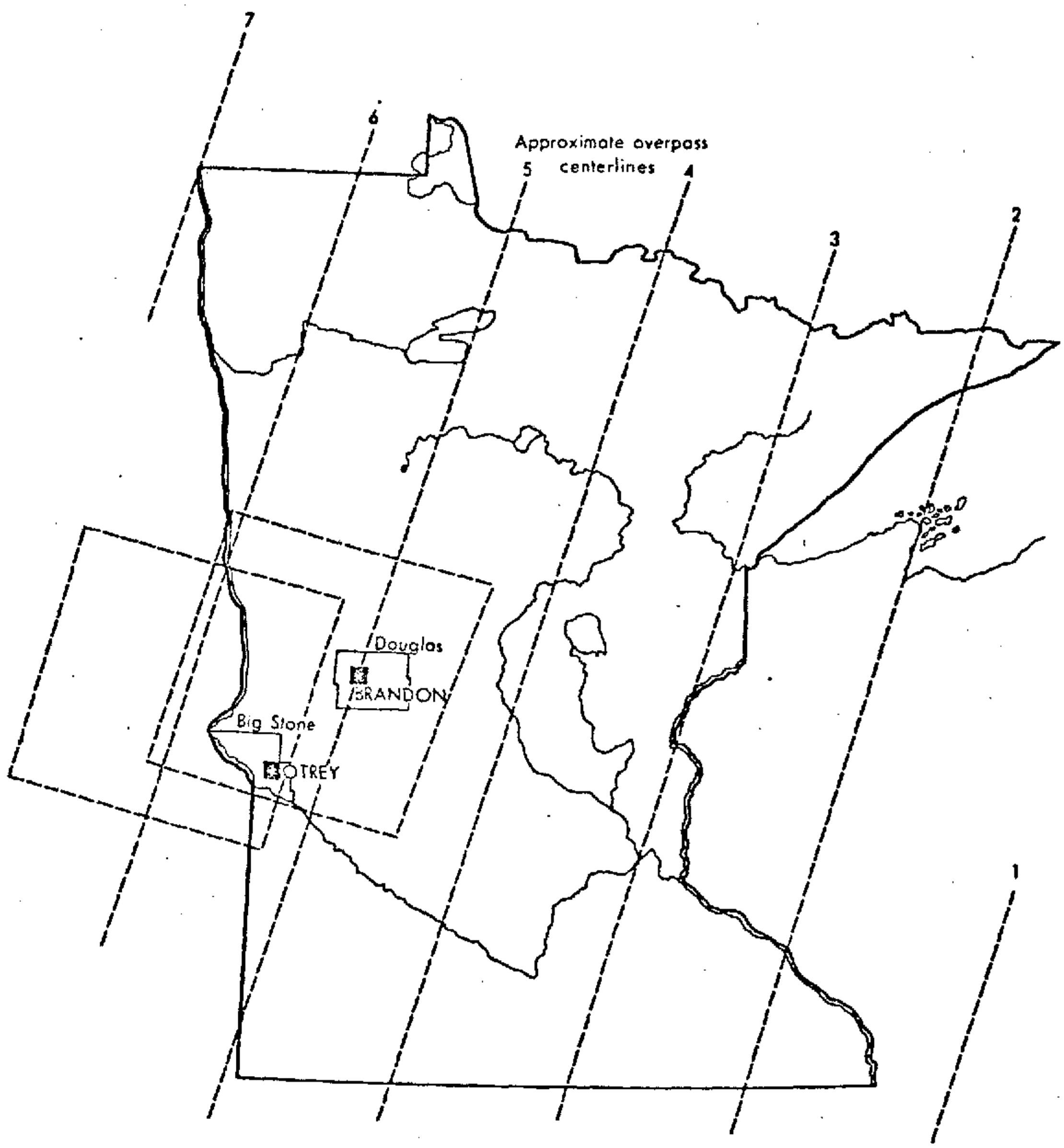


Fig. 3. Location of Study Areas, ERTS overpass centerlines, and ERTS image borders.

The MSS is a line scanning device that images four spectral bands simultaneously through one optical system (Table 1). An array of six sensors per band gathers six lines of information for each west to east movement of an oscillating mirror. Vehicle motion provides flightline advance creating a continuous swath of coverage. During image processing the imaged strip is divided into frames about 115 miles per side, with about ten percent overlap between consecutive frames.

TABLE 1.--MULTI-SPECTRAL SCANNER BANDS

Number	Name	Portion of Spectrum (micrometers)
4	Visible blue-green	.5 to .6
5	Visible red	.6 to .7
6	Near infra-red	.7 to .8
7	Near infra-red	.8 to 1.1

Source: National Aeronautics and Space Administration, Data Users Handbook: Earth Resources Technology Satellite (Greenbelt, Maryland: Goddard Space Flight Center, 1972) p. 3-2.

Data-receiving stations are located at Fairbanks, Alaska; Goldstone, California; and at the Goddard Space Flight Center in Maryland. If the satellite is within range of one of these stations it transmits imaged data to the ground in near real time. When out of range, it records data on board and transmits at a later time. Received data is recorded on digital tapes which may be used directly with various computer procedures or processed via electron beam recorders into various types of photographic images.

This study utilized two types of NASA-produced images. Most interpretation used 70mm positive transparencies which are produced for each spectral band. These images are at a scale of 1:3,369,000 and cover approximately 13,225 square miles of ground scene. NASA also produces 9.5 inch color transparencies at a scale of 1:1,000,000. Bands 4, 5 and 7 are combined with appropriate filters to produce images resembling false-color infrared photographs. Since this type of imagery was available for only a few scenes it was only used once in this study. Other types of products such as scene-corrected images and negatives were available, but were not considered useful.

Originally designed to yield a resolution on the order of 325 to 650 feet, the ERTS-I system is resolving high contrast features of less than 200 feet. Even this better than expected resolution, however, does not make the ERTS system very useful for studying changes in small, isolated features or areas. The real value of satellite imagery lies in its synoptic and repetitive characteristics. Since ERTS-I images cover such extensive areas, large patterns may be easily interpreted. Formerly, such patterns were either not recognized or were only poorly portrayed on aerial mosaics. ERTS-I is proving to be of great value for studying geologic structures, vegetation associations, snowfalls, flooding, turbidity plumes, cloud patterns, and land use changes. Perhaps even more important than the synoptic characteristics of ERTS-I is its ability to yield repetitive coverage. In the past, both ground surveys and those using aerial remote sensing techniques have been severely restricted in their ability to monitor change. In ground surveys shortages of time and money inhibit repetitive coverage. Advances in techniques of gathering data by aircraft have largely negated the time restriction, but high costs still reduce the possibilities of obtaining frequent updating. Since costs of developing satellite systems are incurred by the population at large through the Federal Government, individual users can receive repetitive imagery coverage at very nominal cost. This makes the monitoring of regional dynamic features very feasible for a large number of users.

The Study Area.

Several factors were considered in the selection of a study area for this investigation. These may be divided into three categories: the nature of the questions to be answered, limitations of cloud-free ERTS coverage, and availability of base information and supporting evidence. The major value of small bodies of open water in West-Central Minnesota is use by waterfowl for breeding, production, and migrating functions. Resource managers are very interested in the number of water areas, their acreages (both individual and collective), and fluctuations in these two variables over time. For example, numbers of potholes with water in July has been found to be closely correlated with waterfowl production and is used for establishing fall hunting regulations.[11] The

---

[11]A. D. Geis, R. K. Martinson, and D. R. Anderson, "Establishing Hunting Regulations and Allowable Harvest of Mallards in the United States," Journal of Wildlife Management, Vol. 33 (1969) pp. 848-859.

Minnesota Department of Natural Resources and the U. S. Bureau of Sport Fisheries and Wildlife have each spent nearly ten million dollars acquiring waterfowl habitat in the past two decades.[12] Any information describing where potholes are being lost through drainage or where they are prone to extreme fluctuations (natural or man-induced) would be useful for establishing acquisition priorities and management programs. Delineation of areal fluctuation in larger lakes should be helpful in planning habitat improvement expenditures and in regulating lakeshore development. Some of the basic questions this paper attempts to answer are: How many water areas are there? Can they be accurately mapped from satellite imagery? What is the smallest water area that can be delineated? Does satellite mapping reveal fluctuation regimes? Answering such questions dictates that the investigation must cover fairly extensive blocks of landscape rather than individual water bodies.

A major limitation on the synoptic and repetitive characteristics of ERTS-I is that it is an orbiting platform subject to the vagaries of cloud cover. Although a complete annual sequence of images taken every eighteen days would be very helpful for studying hydrographic fluctuations, such an event would be very unlikely. The number of clear, cloud-free images was an important criterion in selecting areas for study. Orbits #5 and #6 cover much of West-Central Minnesota and have considerable sidelap (Fig. 3).

---

[12] Information on the amount spent by the state of Minnesota was obtained from Minnesota Wetlands, (Map), (St. Paul: Minnesota Department of Natural Resources, Division of Game and Fish, Section of Game, 1973); the amount spent by the Bureau of Sport Fisheries and Wildlife was estimated by Thomas F. Follrath, Chief of Realty Branch during a personal interview on 2/7/74.

This arrangement produced four cloud-free, ice-free images for the eastern part of the area and seven for the western section (Big Stone and Traverse Counties).

An evaluation of new types of imagery requires some source for comparison -- usually referred to as "ground truth." Availability of ground truth limits selection of study areas and its quality determines what statements can be made concerning the new technique. This study has been hampered to some degree by a lack of high quality ground truth. Although five flight lines of high altitude aircraft coverage were flown by NASA in the summer of 1972 over various parts of Minnesota to provide ground truth data, a sixth area in West-Central Minnesota was not covered. This meant that either a system of on-the-spot field observations would have to be arranged or other somewhat dated sources of information would have to be used. The former alternative was rejected for several reasons. The area of interest is located a considerable distance from the Twin Cities, making the costs of repeated field trips coinciding with cloud-free overpasses of the satellite prohibitive. It would also have been difficult to cover more than a few water bodies on the ground. One of the objectives of the study was to be evaluation of satellite imagery for mapping hydrographic features over considerable areas, so this limitation was quite significant. In view of these limitations the use of existing data sources seemed to be the best alternative available. A description of these sources is in the next chapter, they will not be reviewed here. However, the availability of the sources for various parts of West-Central Minnesota was an important consideration in the selection of study areas.

Although several considerations such as study objectives and frequency of cloud-free satellite coverage argued for selection of a study area in Big Stone County, availability of comparative data such as 1:24,000 topographic maps and Department of Natural Resources (DNR) watershed surveys indicated the study area should be located to the northeast in or near Douglas County. A compromise approach was selected. The study is divided into two phases. First, Brandon Township (T129,R39) in Douglas County will be investigated to develop interpretation techniques and evaluate the satellite imagery (Fig. 3). Then Otrey Township (T122,R45) in Big Stone County will be investigated by applying these techniques. Both phases will use ERTS imagery from the period August, 1972 through July, 1973.

Brandon Township is located on the Alexandria Moraine in western Douglas County. This moraine was deposited by the Des Moines Lobe during the Wisconsin period of glaciation and, in the vicinity of Brandon Township, the till is between 400 and 500 feet thick over a base formation of Precambrian metamorphic rock. The drift has high concentrations of calcium, magnesium, bicarbonates, and sulfates which make the surface waters relatively hard. Local relief of 100 to 200 feet gives the area a rolling, hilly appearance with many lakes and potholes occupying depressions. Lenses of clay and sand are sandwiched in the till giving variable water tables ranging in depth from 20 to 100 feet or more. Medium to fine textured prairie border soils predominate and are well drained except in depressions where accumulations of impervious clay materials have sealed bottoms of numerous lakes, potholes, and marshes. Precipitation, averaging about twenty-five inches per year, reaches a peak in the early summer growing season. The combination of rolling topography, fertile soils, and adequate precipitation make general farming the most common agricultural activity. The township is quite representative of landscape conditions in the forest-prairie transition belt of West-Central Minnesota.

Otrey Township is situated in the heart of the Big Stone Moraine which traverses Big Stone County from northwest to southeast. The glacial drift here is of similar origin as that in Brandon, but it is thinner (200 feet thick) and is underlain by a layer of shale in addition to a base of granite rock. Rich, dark, medium to fine textured prairie soils formed under grasslands make the area very suitable for large farms specializing in cash grain crops. Local relief of 80 to 100 feet gives the landscape a gently rolling appearance that is considerably flatter than the Brandon area. Numerous marshes and potholes occupy poorly drained depressions. Large lakes tend to be very shallow (less than fifteen feet), and all surface water is harder, more fertile, and more prone to dramatic fluctuations. Rainfall averages about twenty-four inches per year, but is much more variable than at Brandon. Although the Brandon area still has numerous forested tracts and woodlots, trees in Otrey Township are found only on the margins of lakes, along streams, on farmsteads, or in windrows.

Summary of Methodology and Conclusions.

The study areas just described were investigated to demonstrate the value of data derived from satellite images by unsophisticated, manual interpretation techniques. Most interpretation consisted of projecting ERTS band 7, bulk, 70mm transparencies from the period August, 1972 through July, 1973 onto a screen at a scale of 1:126,720 and delineating water areas on tracing paper attached to the screen. Areas were then numbered and counted, and an area estimate of each was made. All data were tabulated into seven size classes. In Brandon Township the ability of ERTS to inventory average water conditions was demonstrated by comparing ERTS data with data derived directly from high altitude aerial photography and several sources originally derived from low altitude aerial photographs, including a county highway map, topographic maps, DNR lake surveys, and DNR Bulletin #25. Monthly weather information on precipitation and temperature was incorporated when possible to aid the comparison of information obtained in different time frames. Results indicate manual interpretation of ERTS images is quite accurate for open water areas larger than ten acres. Accuracy tends to be best for large, regularly shaped lakes and drops with decreasing size and increasing irregularity of shape. Inventory of water from ERTS images is superior to all other evaluated sources of water information except, perhaps, high altitude aerial photographs. However, in cost terms, ERTS-derived data are superior to all other sources of water information.

An attempt was made in the Otrey study area to evaluate the usefulness of ERTS images for monitoring fluctuating water conditions. Numbers and acreages of water areas were interpreted from seven ERTS images covering the same one year period as in Brandon.

Results were then compared with normal yearly fluctuations of ponds observed by other investigators through field measurement and with recorded fluctuations in monthly precipitation and temperature. Except for a brief anomolous trend at the start of the period, which is probably attributable to early problems with imagery quality and interpretation procedures, trends in aggregated water area numbers and acreages corresponded to trends expected from interpretation of weather conditions.

In both the Brandon and Otrey attempts commission errors were made in interpreting water from ERTS images. Investigation revealed the errors to be misinterpretation of recently plowed dark soils as water. The errors did not seriously affect general conclusions of the study since they were usually small in size and concentrated in the late fall and early spring.

At the outset of the study it was hoped marshy wetlands could also be interpreted from ERTS. Initial investigation of bulk, single band images indicated marshes could not be distinguished from cropland. Receipt of a NASA-produced color composite image enabled a new attempt to be made at detecting marsh. Results indicate only very large marshy areas can be detected from ERTS using the procedures of this study. Open water was also interpreted from this image, and results of this one attempt hint that color images are probably superior to band 7 transparencies for manually detecting water.

CHAPTER II. DATA SOURCES AND METHODOLOGY

A useful evaluation of new technology and techniques must include a comparison of the new with the old. Such a comparison should outline the liabilities of various sources of information as well as the assets. In this case, determining the value of satellite imagery for managing lakes and ponds requires that it be compared with other data sources that are presently being used by public agencies entrusted with management responsibilities. This study utilized, in addition to several types of ERTS-I imagery, high altitude panchromatic aerial photographs and data previously derived from them in the Minnesota Land Management Information System (MLMIS); information derived from low altitude aerial photographs such as topographic maps of the United States Geological Survey (USGS), Minnesota Highway Department county highway maps, a DNR lake inventory, DNR fish and game lake surveys; weather data compiled by the United States National Weather Service (NWS). This chapter will describe each of these source materials and then outline how they fit into the methodological framework of the study.

High Altitude Aerial Photography.

Recent improvements in the quality of aircraft, cameras and film available for civilian use have provided resource managers with an enhanced variety of aerial photography. Previously, available equipment usually restricted aerial surveys to altitudes of under 15,000 feet. This meant that coverage of large areas required numerous overpasses which could take many days or weeks to achieve consistent weather and sun angle characteristics. It also meant very large numbers of photographs, which tended to inflate production, inventory, and interpretation costs. With military declassification of improved equipment in the mid-1960's, high resolution, high altitude aerial photographic coverage of large areas became feasible for resource planners. Through cooperative financing by the Minnesota Highway Department, the Minnesota State Planning Agency, and the Upper Great Lakes Regional Commission complete coverage of Minnesota with such photography was obtained from Mark Hurd Aerial Surveys Inc. Photographs covering the southern half of the state were taken in the spring of 1968 and of the northern half in the spring of 1969. The photographs were taken from a jet at an altitude of 45,000 feet AMG with a Wild RC-8 camera using black and white panchromatic film. A six inch focal length lens was used giving the nine inch square prints a scale of 1:90,000. The following numbered photographs were used in this study:

Otrey twp. - Flight line 2S, Nos. BIK 891, 892, 893
date: 5/5/'68

Brandon twp. - Flight line 28, Nos. BRA 94, 95, 96
Flight line 29, Nos. BRA 71, 72, 73
date: 4/21/'69

In addition to using these photographs directly, data from MLMIS was obtained for comparison. These data consist of the "water" class of land use which was interpreted from the photographs on the basis of dominance within forty acre grid cells of the township and range survey system.[13]

Low Altitude Aerial Photography.

Aerial photographs taken by low flying, propeller driven aircraft have been used by resource managers since the 1930's. This type of remote sensing has been very valuable for studying small areas of interest. When used for investigating large areas, however, they become prohibitively expensive and cumbersome. To obtain extensive areal coverage state resource managers have had to rely on photographs taken by large federal agencies. For the agricultural areas of Minnesota the Soil Conservation Service (SCS) has made their photography available to other users. Such imagery does not always have the best characteristics for certain problems, but since it is often the only imagery available it is used. This study did not directly use low altitude aerial photography, but relied on maps and data compiled by others from such photographs.

DNR's Division of Waters, Soils, and Minerals has produced an inventory of lake basins over ten acres for the state. Most of the information was obtained from low altitude photographs taken in various months from 1938 to 1955. Basins were mapped,

---

[13]For a detailed description of interpretation procedures and the MLMIS, see George W. Orning and Les Maki, Land Management Information in Northwest Minnesota: The Beginning of a Statewide System, Report No. 1 (Minneapolis: University of Minnesota, Center for Urban and Regional Affairs, Minnesota Land Management Information System Study, 1972).

numbered, and planimetered. Results were tabulated by county and published as DNR Bulletin #25.[14] Lake basin area data from this document were used in this study for comparison with surface water acreages derived from ERTS-I imagery.

A second source of data derived from low altitude aerial photography are the fish and game lake surveys of DNR. These are ground surveys conducted with the aid of base maps prepared from low altitude photographs. They have been conducted for the past several decades and utilize many dates of photography. Undoubtedly the same photographs used for the DNR Bulletin #25 inventory have in the past been used for these investigations. Although separate surveys are conducted for individual lakes, this study used summarized area data for lakes in Brandon Township contained in Appendix II of DNR Special Publication #49.[15] The original surveys on file at DNR give depth soundings, detailed ecological information and, in many cases, historical comments. Maps at a scale of 1:7920 (eight inches to the mile) are included with each survey.

The only state-wide coverage of Minnesota on maps of uniform scale are the county highway maps produced by the Minnesota Highway Department. These maps are available at either 1:126,720

---

[14] An Inventory of Minnesota Lakes, Bulletin No. 25 (St. Paul: Minnesota Department of Natural Resources, Division of Waters, Soils, and Minerals, 1968).

[15] Gerald W. Larson, Biological Survey of the West Branch of the Chippewa River, Pope, Stevens, Swift, Douglas, Grant, and Ottertail Counties, Special Publication No. 49 (St. Paul: Minnesota Department of Natural Resources, Division of Game and Fish, Technical Services Section, 1967).

(half inch to the mile) or 1:63,360 (one inch to the mile). The 1:126,720 variety proved to be an adequate base map for maintaining constant scale while interpreting ERTS imagery. This scale is particularly suitable since it approaches the 1:100,000 limit for interpretation from ERTS of high contrast features such as water suggested by USGS.[16] They contain enough natural features (lakes and rivers) as well as cultural features (towns and highways), and have dark printing on a light background which facilitates achieving constant scale and focus with projected ERTS imagery. These maps were originally compiled from low altitude aerial photographs and are, therefore, also used in this study for comparing water areas with ERTS-derived data.

The fourth data source derived from low altitude aerial photography used in this study were 1:24,000 USGS quadrangle maps. Four sheets, Brandon (1966), Quam Lake (1966), Evansville (1969) and Millerville (1969) were used for comparing open water acreages with ERTS-derived data for Brandon Township. Three of the sheets were compiled by photographic means from photographs (presumably SCS) taken in 1965 and the fourth, Evansville, from photographs taken in 1966. Although topographic maps are produced from photographs taken at a particular date, USGS mapping instructions call for an attempt to be made to represent "normal stage"

---

[16]Alden P. Colvocoresses and Robert B. McEwen, "Eros Cartographic Progress," Photogrammetric Engineering, American Society of Photogrammetry, Vol. 39 (1973), No. 12, p. 1304.

conditions:[17]

> The shore line used to represent a natural lake or pond should be that corresponding to a normal stage of water and not necessarily the shore line that is found at the time of the survey, which may be during periods of flood or extreme drought. An effort should be made to ascertain the shore line of the normal stage, as usually marked by a line of permanent land vegetation.

In this study, water conditions portrayed on topographic maps will be considered as representing "normal" or "average" conditions resulting from normal years of precipitation and temperature.

ERTS-I Imagery.

A general description of the ERTS-I satellite system and imagery was given in the introduction and will not be repeated here. A need remains, however, for more specific information about image format. Both the 70mm and 9.5 inch image products have identical layouts (Fig. 4). Relevant information about each image is contained in the annotation block at the bottom. The seven images used in this study each have distinctive characteristics (Table 2).

Climatological Data.

Area fluctuations of water bodies in West-Central Minnesota are directly related to variations in precipitation and temperature. Precipitation on the water surface is the major source of

---

[17] W. M. Beaman, Topographic Instructions of the United States Geological Survey (Washington, D. C.: U. S. Government Printing Office, 1928) p. 243.

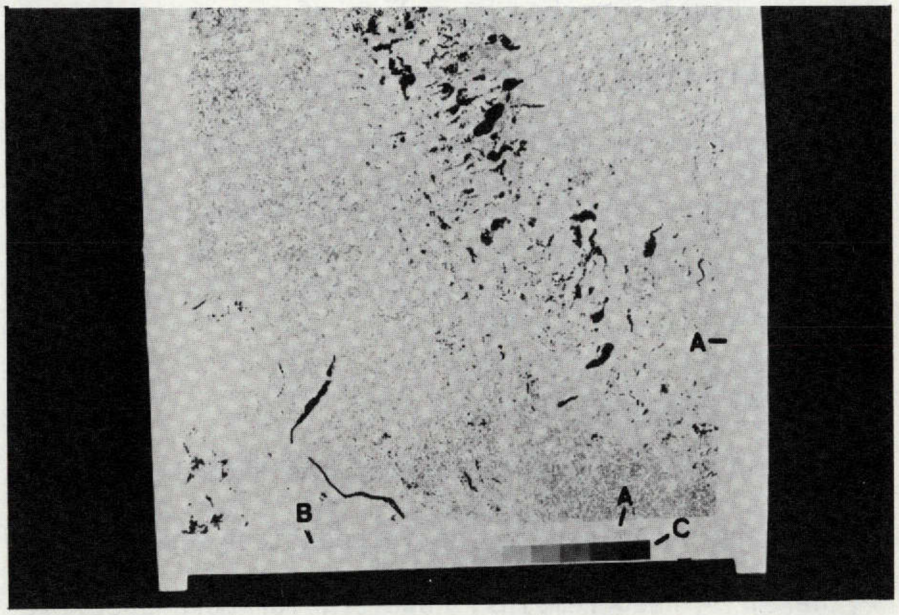


Fig. 4. Layout of 70mm and 9.5 in. image products. Latitude and longitude coordinates at thirty minute intervals are located on all sides of the image (A). An annotation block contains information about date of the image, coordinates of image format center, coordinates of image nadir, spectral band of the image, sun elevation and azimuth angles, spacecraft heading, orbit revolution number, ground recording station, several processing parameters, agency and project identification, day number of image, time of image, and spectral band (B). A fifteen step gray scale is located below the annotation block (C).

Table 2.--DESCRIPTION OF IMAGES

Date Imaged	Image Descriptor	Product Type[a]	Study Twp.[b]	Comments
16 Aug. '72	1024-16432-7	+	*	Clouds cover 70 percent, SE corner clear. No problem with plowed fields or cloud shadows.
16 Aug. '72	1024-16432-4,5,7	-	*	Same as above, colors very bright.
3 Sept. '72	1042-16485-7	+	*	Clouds cover 50 percent in scattered NW-SE strips. No problem with cloud shadows. Plowing is a problem.
21 Sept. '72	1060-16485-7	+	*	No clouds on image. Image slightly overexposed. Water very distinct. Plowing is a problem.
8 Oct. '72	1007-16431-7	+	*,#	Northern 40 percent of image cloud covered. Image slightly underexposed and fuzzy. Plowing is a problem, but no cloud shadow difficulties.
30 May '73	1311-16435-7	+	*,#	Some trouble with plowed fields, but no cloud shadow difficulty. Water very distinct.
17 June '73	1329-16434-7	+	*,#	Sharp image, water very distinct. Some trouble with plowed fields, no cloud shadow problems.
5 July '73	1347-16432-7	+	*,#	Slightly overexposed image made water very distinct. Some trouble with thin clouds over NE corner of Brandon twp. No problem with plowed fields.

[a] 70mm black and white positive transparencies are designated by a +; 9.5 inch color transparency is designated by a -.

[b] Otrey Township is designated by a *; Brandon Township is designated by a #.

Source: Author's interpretation of ERTS images.

water input into the water balance equation of small water bodies in non-urbanized environments, and evaporation from the surface is the most significant component of water loss.[18] Information about precipitation and temperature conditions at the study townships is necessary for a better understanding of the fluctuations in water body areas and numbers observed on ERTS imagery. Data from the NWS station at Alexandria, approximately ten miles southeast of Brandon Township, was considered representative of climatic conditions in the township. For Otrey Township, data from the station at Artichoke Lake, about five miles to the east, was used. Since several other information sources used in this study postulate "normal" or "average" conditions, normals were computed from the data for the period 1941 through September of 1973 to exclude influences of the severe drought period of the 1930's which the NWS includes in its computations of normals. No record of such a severe and extended drought in the area exists for the years after the 1930's, so the conditions in those years may be considered "abnormal" and be excluded from computations of averages.

Methodology.

Much of the research being done with ERTS-I imagery involves sophisticated electronic equipment and procedures. These efforts usually require computer facilities and highly trained personnel.

---

[18] Manson, et. al., op. cit., footnote 6, pp. 16-17.

Such arrangements of machinery and expertise are usually found at large universities and Federal Government research centers, but are frequently not very accessible to many resource managers in state government. One of the primary goals of this investigation was to develop simple manual interpretation procedures that would encourage immediate use of satellite imagery by persons not previously familiar with it. The equipment and procedures used here are familiar to those with aerial photography experience and are not new--only the imagery is new.

Interpretation of 70mm ERTS images was accomplished using a high intensity, fan cooled lantern projector with a twelve inch focal length lens, 3.5 X 4 inch glass slides, tracing paper, hard (4H) pencils, and half inch to the mile county highway maps. A twelve inch lens produces less distortion and is easier to focus than shorter lenses, but requires a fairly large room (at least twenty-five feet long) for projection. The 70mm images are first mounted in clean glass slides with the area to be mapped as near the center of the slide as possible to minimize lens distortion. County highway maps are then either tacked or taped to a suitable dull white, vertical surface at one end of the room. While this is being done, the projector should be turned on with the slide in it to warm everything to operating temperatures. Once these steps are completed, the projector should be positioned at right angle to the map plane at a distance suitable to obtain scale registration of prominent features (lakes, rivers, highways, towns) on the image with the same features on the map. Patience and care should be exercised in obtaining scale and focus, since this is crucial to accurate mapping. When good scale and focus have been achieved, tracing paper that has had the county boundaries traced on it beforehand is aligned over the map. The highway map can now be removed and mapping with the hard pencil can proceed. Square blocks of up to nine townships can be mapped with one set-up using these procedures and still maintain a minimum of distortion. Before mapping, it is helpful to spend a few moments scrutinizing the image to become familiar with its individual characteristics. If water is being mapped, special attention should be given to features such as cloud shadows and freshly plowed dark soil, which have image characteristics resembling water.

The best method for estimating areas in this study seemed to be the use of a grid. Translucent graph paper with ten units to the half inch was chosen because cells would be approximately the same size as the smallest feature to be mapped. In this case, each cell was equivalent to 6.4 acres. Using a light table, the original mapping was traced onto the grid paper, lakes were numbered, and areas were tabulated using a table-mounted, variable power microscope and a small electronic calculator.

Interpretation of the high altitude aerial photographs was slightly different. Tracing paper was taped on one photograph of a stereo pair and mapping was done while viewing the photographs through a mirror stereoscope. Since the tracing paper is somewhat translucent, the stereo effect remains, which greatly aids interpretation. All wet areas were mapped as either open water or marsh. Once interpretation was completed, the maps were traced on graph paper and numbered. A mapograph was used to reduce original maps to the same scale as the ERTS mapping so that the same numbering system could be used. Where applicable, the numbering system of DNR Bulletin #25 was used so that results would be comparable. The same area estimation procedures described above were used, except that, with the larger scale, each cell represented 3.3 acres.

Area estimates of water represented on county highway maps and the four topographic maps covering Brandon Township were made in much the same manner. Water areas on topographic maps were numbered directly on the maps, and area estimates were made by overlaying the grid paper on them.

Interpretation of the color image used in this study was done in a somewhat different manner, since the 9.5 inch image could not be mounted in a slide and interpreted, as were the 70mm images. The image was placed on a light table and color slides were taken with a 35mm camera. A zoom lens projector was then used to project the slide through a piece of mounted plate glass with frosted acetate taped to the far side. This provided an image which could them be interpreted in much the same manner as the 70mm products.

Originally, this study intended to map both open water and marshy areas from ERTS-I imagery. Soon after initiation of interpretation, however, it was decided that the visual-manual approach being used would be inadequate for mapping marsh vegetation from the imagery at hand. Only extremely large areas of marsh vegetation were detectable, and even these had tones closely resembling various types of cropland. Color images seemed to hold some promise of resolving this problem, so mapping of marsh was attempted on the one color image that was interpreted. The extra photographic step involved in producing the color slide, however, somewhat degraded the resolution of the image, compounding the problem of distinguishing small marshy areas. In light of these circumstances, primary emphasis of the study was shifted to mapping of open water. There may be some compensation in the fact that many of the areas of marshy vegetation in West-Central Minnesota have substantial areas of open water in the early spring and may then be detected from ERTS imagery.

CHAPTER III.

BRANDON TOWNSHIP: AN EVALUATION OF THE IMAGERY

Attributes of Information Sources.

Management of lakes and ponds, which can range from passive protection or preservation to active attempts at improvement, requires knowledge of where those features are. If the features are relatively stable over time, as are, for example, the lakes of the Laurentian Shield of northeastern Minnesota, a single inventory or mapping may be sufficient. For such areas USGS topographic maps are entirely adequate for most purposes. In other areas, such as West-Central Minnesota, where lakes and ponds fluctuate greatly in both area and numbers, conventional information sources become inadequate. Although present aerial photography is sufficient to detect very small water features, its use is restricted by cost and limited areal coverage per image.[19] This study found that when used for inventories such as DNR Bulletin #25, DNR lake surveys, or USGS maps, aerial photographs leave much to be desired.

ERTS-I satellite imagery can supply useful information about lakes that is in some respects better than existing sources. A very important attribute of ERTS imagery is that each image covers

---

[19]Water areas as small as one acre were detected from the high altitude aerial photography used in this study. Areas of several tenths of an acre may be detected on low altitude aerial photography.

a ground scene that is 115 miles on a side, for a total of about 13,225 square miles. This means very few images are required for complete coverage of extremely large areas with resultant reduction of costs associated with storage and handling. Large areal coverage is also valuable in providing a synoptic framework that is not available on any other type of imagery. Probably the most valuable characteristic of ERTS imagery is that it is repetitive every eighteen days. This enables time sequence studies of changing phenomena to be conducted over large areas. Previously, such studies required field work and were severely restricted in areal extent. An added benefit is that ERTS imagery is readily available at quite nominal cost.[20]

Although the attributes outlined above seem very attractive, ERTS imagery has several important limitations that must also be considered. Foremost is resolution. Techniques used in this study resulted in scattered detection of open water areas less than five acres and only marginally acceptable detection rates for water areas of five to ten acres in size. In addition, areas of marsh vegetation were much more difficult to detect than expected. A final shortcoming is that satellite imagery is more susceptible than aerial photography to varying atmospheric conditions. Aerial photographs are taken when conditions are optimal. Satellite images are taken at specified times regardless of conditions. Many satellite images

---

[20]Information on the availability and cost of various ERTS-I images may be obtained by contacting the EROS Data Center, Sioux Falls, South Dakota, 57198.

are obscured by clouds, while others vary in quality according to changing atmospheric haze conditions.

To evaluate the relative attributes of satellite imagery in comparison with other information sources, all available cloud-free ERTS-I imagery from ice-free periods between August, 1972 and July, 1973 were interpreted for open water (band 7).[21] This amounted to one image in the fall and three in the spring (Table 2). Numbers of open water areas and their acreages were determined using the techniques described in the preceding chapter. The same information was similarly collected from a Douglas County Highway Map, DNR lake surveys, DNR Bulletin #25, and topographic maps. All these sources were assembled from low altitude aerial photography. In addition, high altitude photographs taken on April 21, 1969 were interpreted for number of open water areas and their acreages. Acreages of water from the MLMIS data bank, which used these same photographs, were obtained for comparison.[22] These data were tabulated in seven size classes for analysis (Table 3).

Detectability of Open Water.

Although precise ground truth information obtained coincident with ERTS-I overpasses of Brandon Township is lacking, a reasonable

---

[21]Band 7, which images the near infrared portion of the spectrum from .8 to 1.1 microns, is the best band for interpretating water because growing vegetation reflects strongly and water absorbs highly in this portion of the spectrum, creating maximum contrast between water and the surrounding environment.

[22]MLMIS used a "dominance" criteria within forty acre parcels. For a detailed evaluation of the methodology employed by MLMIS for land use classification, see Joseph Stinchfield, "A Statistical Evaluation of the Minnesota Land Management Information Systems Land Use Study," unpublished Master's thesis, University of Minnesota, 1972.

evaluation can be made by comparison with topographic maps and high altitude aerial photography. Relevant weather information is also helpful for a better understanding of water conditions.

Since topographic maps are frequently used in water planning and are supposed to represent "normal" conditions (introductory chapter), they were employed in this study as the major source of base information. Four 7.5 minute quadrangles were required for complete coverage of the township, but about seventy percent was covered on the Brandon sheet alone. This sheet and two of the three remaining sheets were compiled from low altitude photography taken in 1965; the last sheet, covering a small area in the northeastern corner of the township, from 1966 photography. Since SCS flew the area in the same years, the USGS probably used SCS photography for their topographic mapping.[23] SCS photography is generally flown in the early part of the growing season, which would be late June or early July in this area. Since the spring and early summer of 1965 had slightly cooler than normal temperatures and much higher than normal precipitation, both the number and sizes of lakes and ponds could be expected to be considerably above normal (Fig. 5). If lakes on the topographic maps were not completely "normalized" in the mapping process the bias should be toward larger acreages and greater numbers - especially for the small, shallow water features whose numbers and size are most closely linked to weather conditions.

---

[23]An attempt to establish exactly what photography was used was not successful.

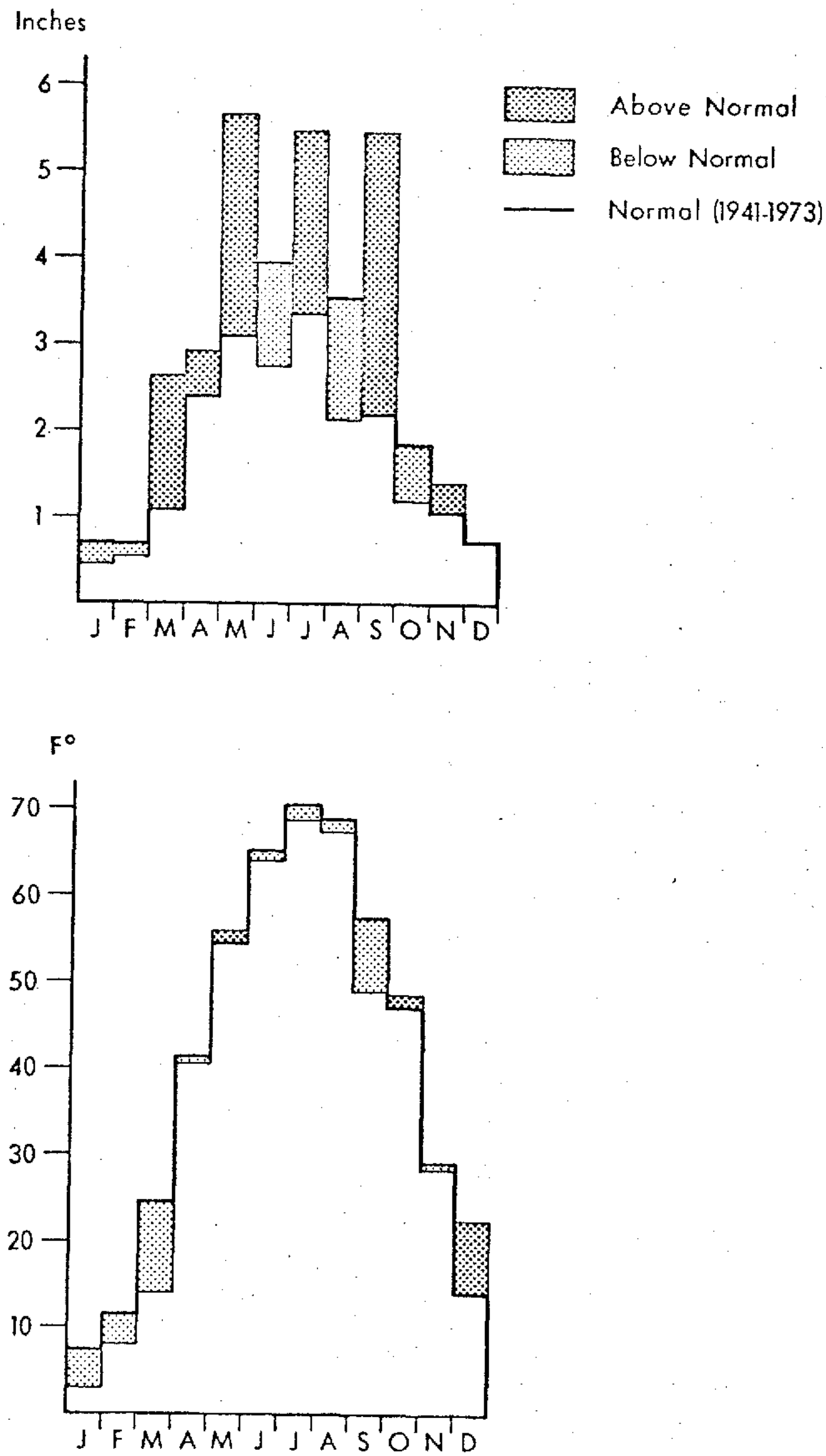


Fig. 5. Total monthly precipitation and mean monthly temperature at Alexandria--1965.

High altitude aerial photographs taken on April 21, 1969 provide another source of comparative information. Interpretation of water from these images must be regarded as typifying very wet conditions. Rainfall in the fall of 1968 was above normal and was followed by one of the most severe winters on record. Unusually cold weather and heavy snowfall of long duration and high water content combined with above normal temperatures and precipitation in early April to produce severe flooding in many parts of the Upper Mississippi and Red River drainage systems (Fig. 6). The floods forced 25,000 people from their homes in the Midwest and caused 175 million dollars damage.[24] Runoff which caused the flooding must also have filled many small depressions in the landscape and expanded the surface area of larger ponds and lakes.

A comparison of the two sources reveals some startling discrepancies. In the 0-4.9 acre size class approximately four times as many water areas were detected on the photos as exist on the topographic maps (Table 3). The difference continues at multiples of two or three to one through classes up to 74.9 acres. In larger lakes the difference is manifested in generally larger sizes for particular lakes. Overall, the photos reveal more than three times more water features covering thirty percent more area. Although some of the difference is due to the wetter conditions prevailing when the photos were taken, part may be the result of definitional problems. The topographic maps have many areas of

---

[24]Elmer R. Nelson, "Snowmelt Floods in the Red River of the North, Upper Mississippi, and Missouri Basins," Climatological Data, National Summary, Environmental Science Services Administration, Vol. 20 (1969), No. 4, p. 197.

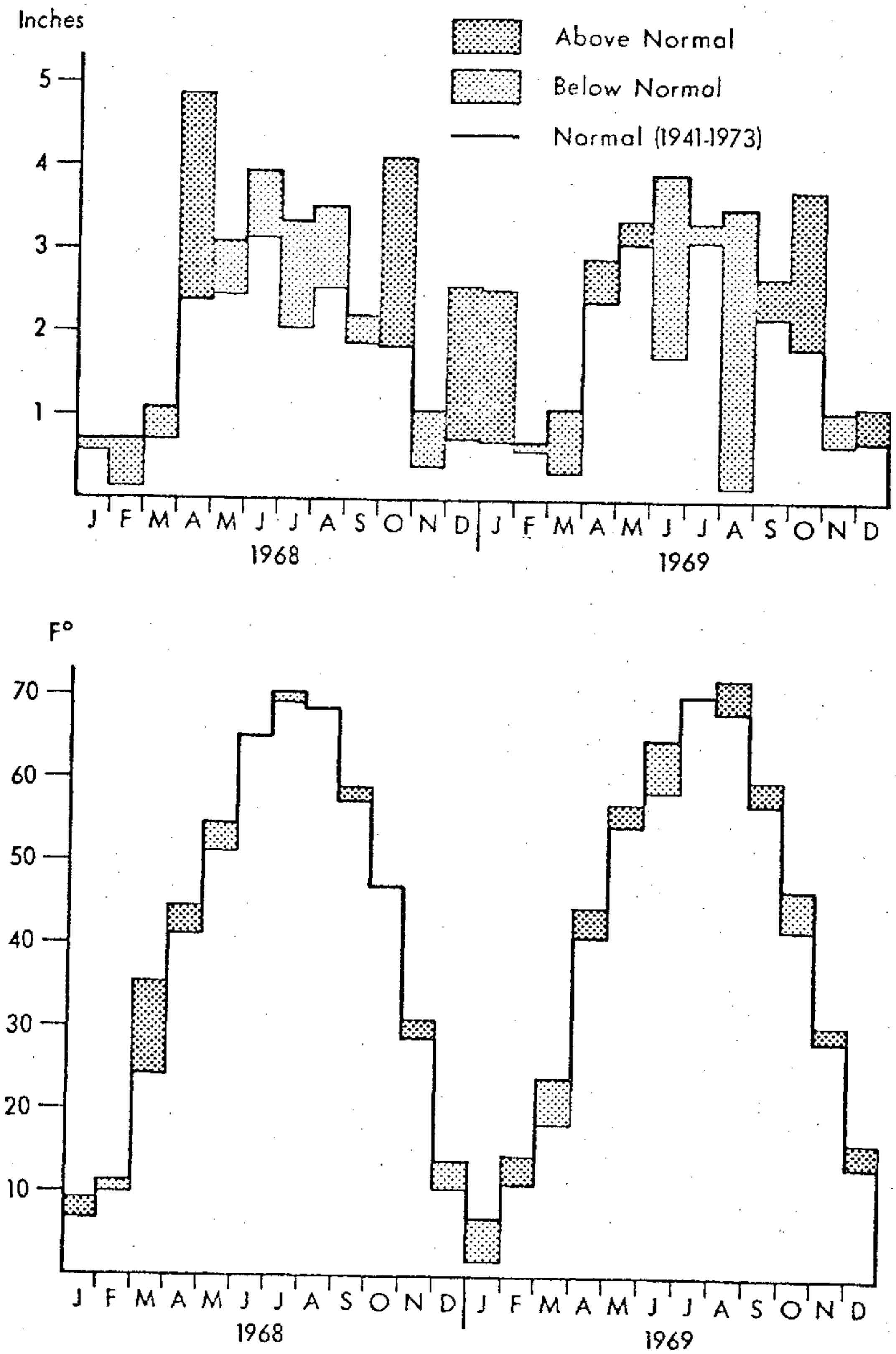


Fig. 6. Total monthly precipitation and mean monthly temperature at Alexandria in 1968 and 1969.

TABLE 3.--NUMBER AND ACREAGE OF OPEN WATER AREAS: BRANDON TOWNSHIP

Source		Size Classes (acres)							
		0-4.9	5.0-9.9	10.0-14.9	15.0-19.9	20.0-74.9	75.0-199.0	200.0+	Total
Co. Hwy. Maps	Number	-	-	-	-	3	9	6	18
	Acres	-	-	-	-	151.1	1216.3	2674.7	4042.1
DNR Lake Surveys	Number	-	-	-	-	-	10	3	13
	Acres	-	-	-	-	-	1474.1	1830.0	3304.1
DNR Bulletin #25 (basins)	Number	-	-	1	4	7	9	5	26
	Acres	-	-	12.0	67.0	203.0	1223.0	3054.0	4559.0
USGS Topo. Maps	Number	28	6	3	3	3	9	4	56
	Acres	51.2	47.4	37.1	51.9	119.3	1186.7	2085.1	3578.7
1969 Aerial Photos	Number	125	15	9	8	10	9	6	182
	Acres	253.0	101.3	188.2	132.9	251.5	1162.7	2674.7	4684.3
MLMIS Water	Number	-	-	-	-	-	-	-	-
	Acres	-	-	-	-	-	-	-	3800.0
ERTS Inventory	Number	22	33	9	4	10	8	3	89
	Acres	70.9	238.1	109.3	64.7	407.4	1050.2	1403.9	3344.5
Corrected ERTS	Number	15	19	4	3	5	8	3	57
	Acres	48.7	149.4	44.0	48.1	202.1	1050.2	1403.9	2946.7

Source: Each source is explained and documented in the text.

marsh portrayed on them. During periods of very high water levels, as occurred in 1969, growth of stands of emergent vegetation is inhibited resulting in larger areas of open water.[25] USGS interpreters probably considered marsh to be the normal condition of such areas and did not map them as open water. This situation, coupled with the filling of many small, normally dry depressions and the expansion of larger lakes, makes the difference between the topographic maps and the 1969 aerial photographs comprehensible.

The detection of hydrographic features from the four dates of ERTS-I imagery varied according to changing weather conditions. The spring and summer of 1972 were characterized by abnormally high amounts of precipitation. March, May, and June were months with double the normal amounts of precipitation (Fig. 7). With temperatures at or slightly below normal, evaporation was not excessive and high water conditions prevailed into the fall. A district conservationist for the SCS stated that "Rainfall in T-129, R39 (in fact the entire County of Douglas) in 1972 was far above normal. Residents claim at least in the last 50 years [sic]. As a result, lake levels were as much as 24 inches above their normal height creating much shoreline erosion and damage."[26] The spring and summer of 1973, in contrast, were periods of generally below normal precipitation and persistently above normal temperatures.

---

[25]Frantz Ruttner, Fundamentals of Limnology (3rd ed., Toronto: University of Toronto Press, 1963), p. 181.

[26]Personnal correspondence with Thomas F. Fischer, District Conservationist with the SCS in Alexandria, dated Nov. 27, 1973.

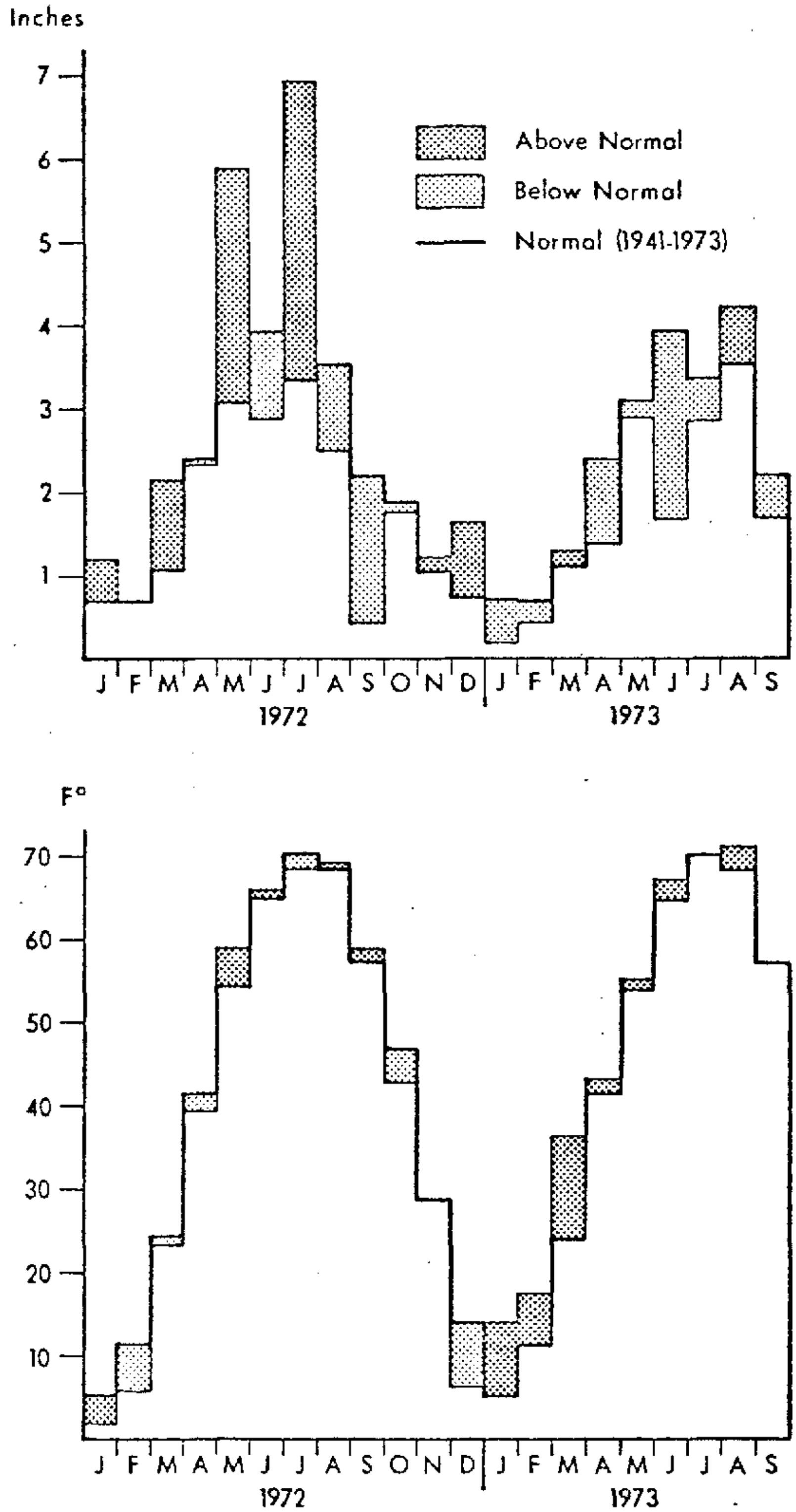


Fig. 7. Total monthly precipitation and mean monthly temperature at Alexandria in 1972 and 1973.

These dynamic conditions are reflected in the interpretation of water from ERTS (Table 4). The October 8 data are inflated because of errors which will be explained in the next paragraph. The number of water areas and their acreage for that date were approximately equal to conditions the following May 30. After May, dryer and warmer weather resulted in contraction in the number of water areas and their acreage. Total acreage dropped consistently in June and July. By July 5 nearly 500 acres less water was detected than on the previous October 8. A more thorough analysis of the ability of ERTS-I to monitor fluctuations in water conditions will be presented in the next chapter on Otrey township for which more dates of satellite coverage were available. Considerable variation occurred in the number of water areas detected in the two size classes less than ten acres. This is a function of the threshold of detection, which includes the tendency to make considerable detection errors under certain conditions.

Recently plowed, dark soils exhibit reflectance characteristics sufficiently close to water to cause them to be misinterpreted as water (Figs. 8 and 9). Interpretation maps from each ERTS image were compared with water mapped from the 1969 photographs. Since those photographs were taken at a time of very high water levels in early spring and have high resolution, it was assumed that ERTS mapping would reveal only water areas mapped from the aerial photographs. Field checking in September of 1973 confirmed this when it was found that all misinterpreted areas were fields. Such mistakes appear to be especially significant when fields are plowed in the autumn (Table 5). On October 8, errors were present

TABLE 4.--NUMBER AND ACREAGE OF OPEN WATER FEATURES DETECTED FROM ERTS: BRANDON TOWNSHIP

		Size Classes (acres)							
Image Date		0-4.9	5.0-9.9	10.0-14.9	15.0-19.9	20.0-74.9	75.0-199.0	200.0+	Total
8 Oct. '72	Number	5	19	7	5	10	8	3	57
	Acres	15.3	141.0	86.4	81.9	457.9	1013.1	1655.1	3450.7
30 May '73	Number	8	8	5	3	4	7	4	39
	Acres	28.3	51.8	59.5	46.8	208.6	898.1	1950.0	3243.1
17 June '73	Number	13	11	4	1	4	9	2	44
	Acres	41.7	62.8	49.2	16.0	185.0	1276.2	1467.6	3098.5
5 July '73	Number	5	15	2	2	5	7	3	39
	Acres	15.5	108.2	21.7	37.8	257.4	924.9	1605.8	2971.3

Source: Interpretation of ERTS images by author.

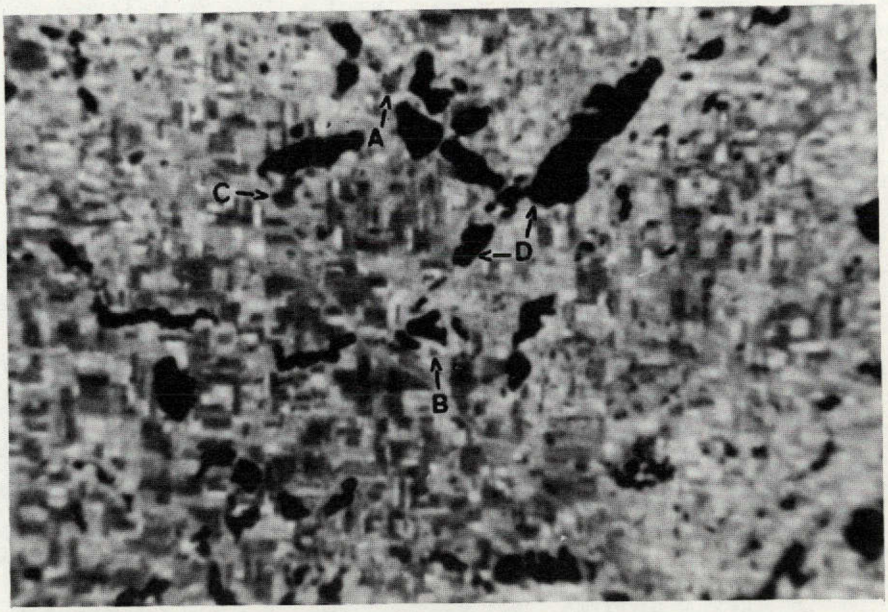


Fig. 8. Examples of plowed fields misinterpreted as water in Brandon Township from ERTS image 1311-16435-7 of 30 May '73. Open water of lakes absorbs heavily in the band 7 spectral area and produces a very dark signature (D). Some plowed fields exhibit a dark signature and are occasionally misinterpreted as water (A and B). Marshes resemble fields and are difficult to detect unless they are large (C).

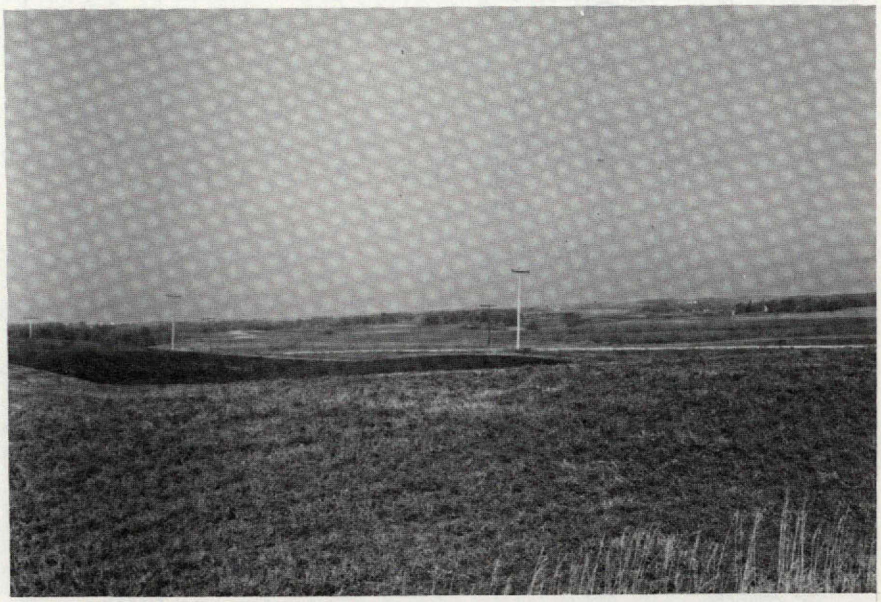


Fig. 9. Ground photograph (taken in Nov., 1973) of a field in Brandon Township misinterpreted as water on ERTS image 1311-16435-7 of 30 May '73. Plowed, dark soil (background) occasionally resembles small water areas on some ERTS images (A in Fig. 8).

TABLE 5.--NUMBER AND ACREAGE OF MISINTERPRETED AREAS: BRANDON TOWNSHIP

Image Date		Size Classes (acres)							
		0-4.9	5.0-9.9	10.0-14.9	15.0-19.9	20.0-74.9	75.0-199.9	200.0+	Total
8 Oct. '72	Number	2	8	5	1	5	-	-	21
	Acres	8.3	55.1	65.3	16.6	236.0	-	-	381.3
30 May '73	Number	-	3	-	-	-	-	-	3
	Acres	-	16.0	-	-	-	-	-	16.0
17 June '73	Number	8	2	1	-	-	-	-	11
	Acres	25.5	10.2	10.2	-	-	-	-	45.9
5 July '73	Number	-	1	1	-	-	-	-	2
	Acres	-	6.4	10.2	-	-	-	-	16.6
Total	Number	10	14	7	1	5	-	-	37
	Acres	33.8	87.7	85.7	16.6	236.0	-	-	495.8

Source: Interpretation of ERTS images by author.

in all size classes less than seventy-five acres and were particularly troublesome in the 20.0-74.9 acre class in which five areas covering a total of 200 acres were incorrectly mapped. Some mistakes were made in the interpretation of the remaining three images, but they were confined to the size classes less than fifteen acres and accounted for relatively insignificant acreages.

Since the ground truth information corresponding to specific dates of ERTS imagery was not available, evaluation of interpretation for each date was not possible. An attempt was made to determine the value of ERTS for developing a general inventory of ponds and lakes. Some water areas were detected only on one of the four dates of imagery. Others were detected several times, while still others were detected on all four dates (Fig. 10). To arrive at a measure of overall detection, every water area that was detected at least once was tabulated with its measured acreage. Acreages of water areas detected more than once then were averaged. The result is a total inventory of water areas by average acreage (Table 3).

A comparison of these average values from ERTS with the open water displayed on topographic maps gives an indication of how well ERTS can provide an inventory of average surface water conditions. The totals by size class are somewhat misleading, since they contain interpretation errors described above, but several conclusions still may be drawn from them. First, the threshold of detection using the methods described in this study is less than five acres. Data for individual water areas indicate the limit is about two acres. This compares favorably with the 2.2 acre lower limit obtained by

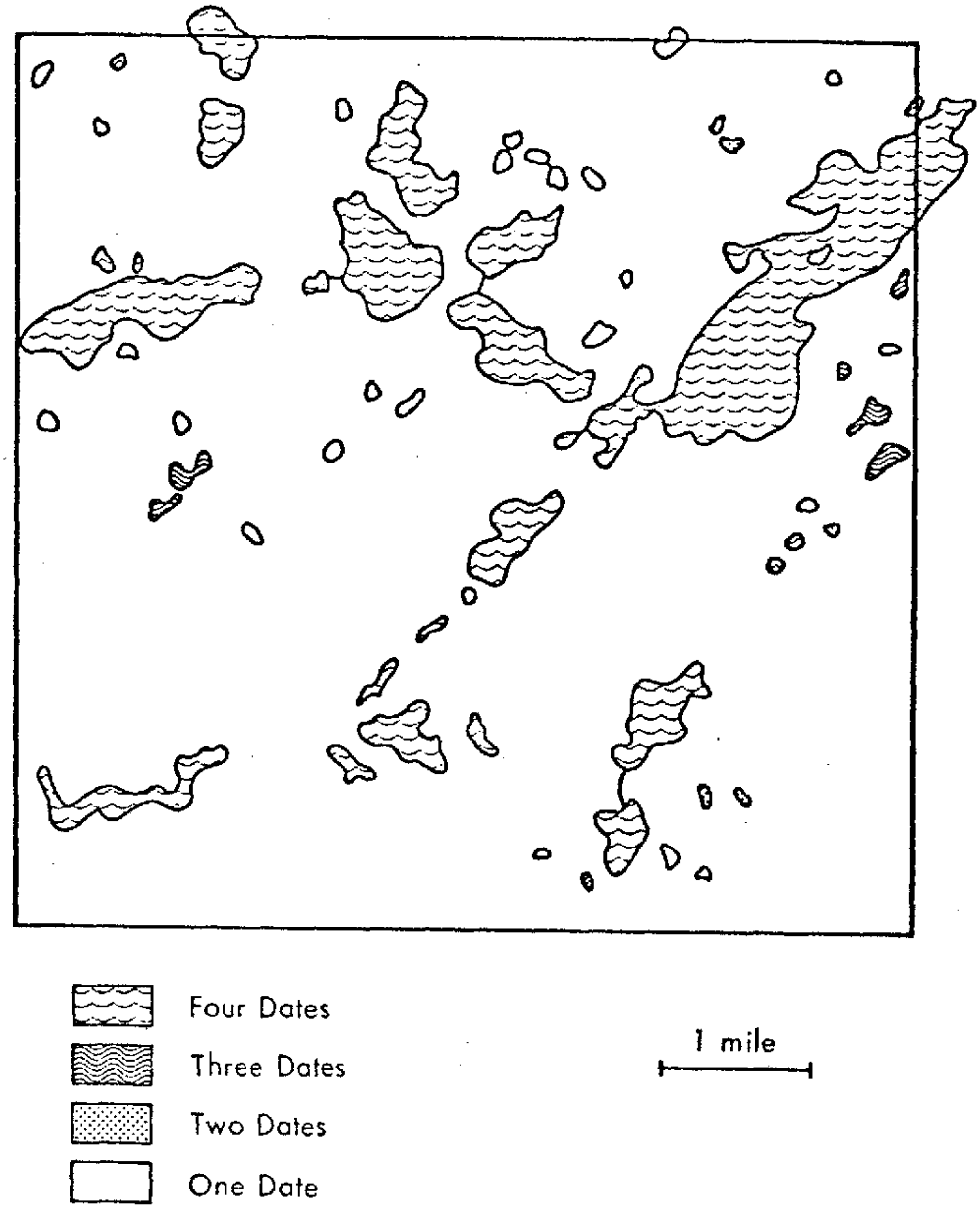


Fig. 10. Progressive detection of water in Brandon Township from four ERTS images. Open water in large lakes is detectable on any ice-free, cloud-free image. Detection of smaller water areas often requires several images, including an image in April, May, or June, when the amount of open water and its contrast with surrounding healthy vegetation are both maximal.

investigators working on detection of small water bodies in North Dakota.[27] They used computerized density slicing techniques on ERTS digital tapes. A "proportion estimation" technique has also been developed to estimate the amount of water contained in picture elements (pixels) which contain a combination of water and other features, and shows promise of improving water acreage estimates.[28]

A second observation is that topographic map acreages tend to be inflated for large lakes. Totals by size class give only a hint of this, since different numbers of lakes are represented in the two largest classes. Investigation of acreages of all lakes over seventy-five acres reveals that topographic map sizes were high for each of the thirteen lakes involved. This is probably due to the very wet conditions which prevailed in the spring and summer of 1965 when the aerial photographs from which the topographic maps were compiled were taken.

Numbers of areas interpreted from ERTS as water and the corresponding acreage values are somewhat misleading in the smaller size classes due to the existence of interpretation errors. When the numbers and acreages of misinterpreted areas are subtracted from the size class totals, direct comparison with topographic map

---

[27]Edgar A. Work, Jr., David S. Gilmer, and A. T. Klett, "Utility of ERTS for Monitoring the Breeding Habitat of Migratory Waterfowl" (paper presented at the Third ERTS Symposium, Washington, D. C., Dec. 10-14, 1973), (Photocopied).

[28]William A. Malila and Richard F. Nalepka, "Advanced Processin and Information Extraction Techniques Applied to ERTS-I MSS Data" (paper presented at the Third ERTS Symposium, Washington, D. C., Dec. 10-14, 1973), (Photocopied).

figures is possible. The most striking result is that the corrected total number of water areas detected from ERTS is nearly identical to that portrayed on topographic maps (Table 3). All water areas of ten acres or more on the topographic maps were detected from ERTS. For water areas less than ten acres the two sources were not as comparable. Although ninety-six percent of the water areas of five acres or more on topographic maps were detected from ERTS, fourteen additional water areas were mapped. The topographic maps indicated these areas as marsh. Topographic maps contain twenty-eight water areas less than five acres, while ERTS detected fifteen. But only eight of these were the same areas. The rest were areas that were mapped as marsh on the topographic maps. It appears that USGS interpreters tended to map as water only those areas under five acres with definite basins and shorelines. Small areas of open water in the midst of larger marshy areas were mapped as marsh. Interpretation of open water from ERTS, in contrast, reveals all detectable open water, but can obtain only scattered detection of areas less than five acres.

ERTS-I Imagery as an Inventory Tool.

The foregoing analysis demonstrates that ERTS-I imagery is probably a slightly better source of information on open water areas greater than five acres than 1:24,000 topographic maps. An even better appreciation of the value of ERTS imagery as a water management tool is obtained when an evaluation is made of several other currently available information sources.

County highway maps are the only map coverage at constant scale available for the entire state. They are a frequently updated source of information about man-made features of the landscape, but are not very accurate portrayals of natural features such as surface water. In Brandon Township, the Douglas map did not show any water bodies less than twenty acres, but their size was somewhat inflated. This gave a much larger water acreage total for the township than was obtained for all size classes from the topographic maps or ERTS. Although water information on these maps is taken from low altitude aerial photographs, apparently little effort is made at accurately mapping such natural features.

Probably the best source of very detailed information on individual water bodies is the collection of DNR lake surveys. Because the surveys involve extensive field collection of information, they are expensive and time consuming. This has restricted the surveys to large (over seventy-five acres in Brandon Township) water bodies. For water bodies over seventy-five acres, acreage data in the surveys (taken from low altitude aerial photographs) compare quite favorably with those derived from topographic maps, but are thirty-five percent larger than acreages measured from ERTS imagery (Table 3).

The most widely used source of surface water information on a state-wide basis is DNR's Bulletin #25. This document was intended to be a complete inventory of lake basins over ten acres in the state. A basin would not necessarily have to contain water to be included, and, in fact, many dry basins were inventoried. As the introduction to the bulletin states, "Lakes, for the purposes of this inventory, include all natural enclosed depressions 10 acres or more in area, which have substantial banks capable of containing water and which are discernible on aerial photographs."[29] In Brandon Township, Bulletin #25 lists twenty-six basins with a total area of 4559 acres. This is four more basins than were portrayed as having water on the topographic maps and twenty-nine percent more acreage. It is nearly fifty-five percent more acreage than was interpreted from ERTS-I images. This document is widely used (and frequently misused) as an authoritative source of locational and size information about Minnesota's "water" or "lakes" when it in fact bears only partial resemblance to the actual water resources.

The final source of information about surface water with which ERTS water acreages were compared was the MLMIS. This data system is based upon dominant land use within forty acre parcels of the land survey system. In Brandon Township the "water" class was assigned to ninety-eight parcels. The "dominance" criterion meant small water areas were not represented. Since the high altitude aerial photographs used in this study were the same ones used in the MLMIS inventory, the best understanding of the consequence of employing a dominance criterion can be gained by comparin results of the two studies. When the number of parcels interpreted as water in the MLMIS is multiplied by a factor of forty the resulting area, 3800 acres, is nineteen percent less than the

[29]Op. cit., footnote 14, p. 4.

acreage interpreted from the same photographs for this study. The system cannot provide data about the number of individual water areas or their sizes unless computer-generated maps are manually interpreted for that purpose. MLMIS information appears to be most useful on a multi-county or state-wide scale.

CHAPTER IV.

OTREY TOWNSHIP: AN APPLICATION OF THE IMAGERY

The Problem of Hydrographic Fluctuations.

The preceding chapter was an evaluation of ERTS-I imagery as a research tool. It analyzed the usefulness of ERTS 70mm band 7 bulk transparencies for detecting and measuring surface water features using the manual interpretation procedures described in the second chapter. Because of limited availability of other forms of ERTS imagery (such as 9x9 inch bulk and color-combined transparencies) at the time of investigation, it was not possible to evaluate other types of interpretation for Brandon Township. A few of these images, were, however, available for Otrey Township. A slightly modified manual approach was used to interpret both water and marsh from a color image. It will be described briefly after a discussion of an application of the 70mm manual approach to discerning hydrographic fluctuations in Otrey Township.

Otrey Township differs from Brandon in several respects, making it a better area in which to study hydrographic fluctuations. The land is flatter. Whereas lakes in Brandon Township vary in depth to ninety feet or more, putting them into contact with the stabilizing influence of the regional water table, those in Otrey are generally less than ten feet deep. They are perched above the regional piezometric surface. Being further west, Otrey receives less precipitation with more variability. This combination of shallow lake basins and variable precipitation which reaches a peak in late spring and early summer makes Otrey Township a good area to study changes in the numbers and areas of surface water features.

In order to evaluate hydrographic fluctuations detected from ERTS imagery, the physical land resource and water regime must be understood. An extensive recent study of small lakes and ponds in central Minnesota developed several general conclusions about small ponds and lakes in glacial drift.[30] The investigators found the mixture of impermeable clay and organic sediments comprising the bottom material of such water bodies permits relatively little seepage into ground water systems, averaging about fifteen to twenty percent of the total water loss for a typical Minnesota pothole. The glacial drift surrounding most potholes, in contrast, is quite permeable and permits rapid infiltration of overflow water during extremely wet periods. When water bodies expand in area during periods of high spring runoff or abnormally heavy precipitation, they tend to quickly return to normal size as the excess water percolates into the soil. This condition should also apply to thousands of small, normally dry depressions in the landscape. Since such areas do not normally contain water, a bottom "seal" has not formed. They are ephemeral features associated with abnormally large amounts of precipitation or runoff.

A second major conclusion of the study is that under normal conditions there is little run-in to water bodies from their local watershed. Exceptional conditions are rapid melting of heavy snows

---

[30] Manson, et. al., op. cit., footnote 6.

in early spring when the ground is still frozen, heavy precipitation of short duration, and existence of a watershed greatly altered by humans with impermeable surfaces and ditching.

The above study concludes that the primary source of water input to small lakes and potholes is precipitation on the surface, and the predominant water loss component is evaporation from the water surface. This ties fluctuations of such features to changing weather conditions throughout the seasons. Undoubtedly, the slightly deeper, larger lakes can be expected to be somewhat less affected by long term changes in climate such as the drought of the 1930's. Otrey Lake, for example, was "dry from 1934 to 1937, and good crops were raised on the area during this period."[31]

The findings outlined above led the investigators to state:[32]

> The normal regimen of ponds and lakes, therefore, is a sharp rise at the spring breakup and during a period of relatively high precipitation in May and June, followed by a steady decline during the summer and early autumn. As evaporation declines in October and November, the water level in open bodies declines slowly or becomes nearly stable and remains so until spring.

Existence of such a "normal" regimen is reflected in the vertical fluctuations of water depths in sample lakes of the above study (Fig. 11).[33] All of the water areas exhibited a sharp rise in levels in March, April, and May of 1966, followed by a gradual

---

[31] Waterfowl and Muskrat Habitat Survey of Otrey Lake - Big Stone Co. (St. Paul: Minnesota Department of Conservation, Division of Game and Fish, Bureau of Wildlife Development, 1952), (Photocopied).

[32] Manson, et. al., op. cit., footnote 6, p. 34.

[33] E. R. Allred, et. al., Continuation of Studies on the Hydrology of Ponds and Small Lakes, Technical Bulletin No. 274 (St. Paul: University of Minnesota Agriculture Experiment Station, 1971), p. 58.

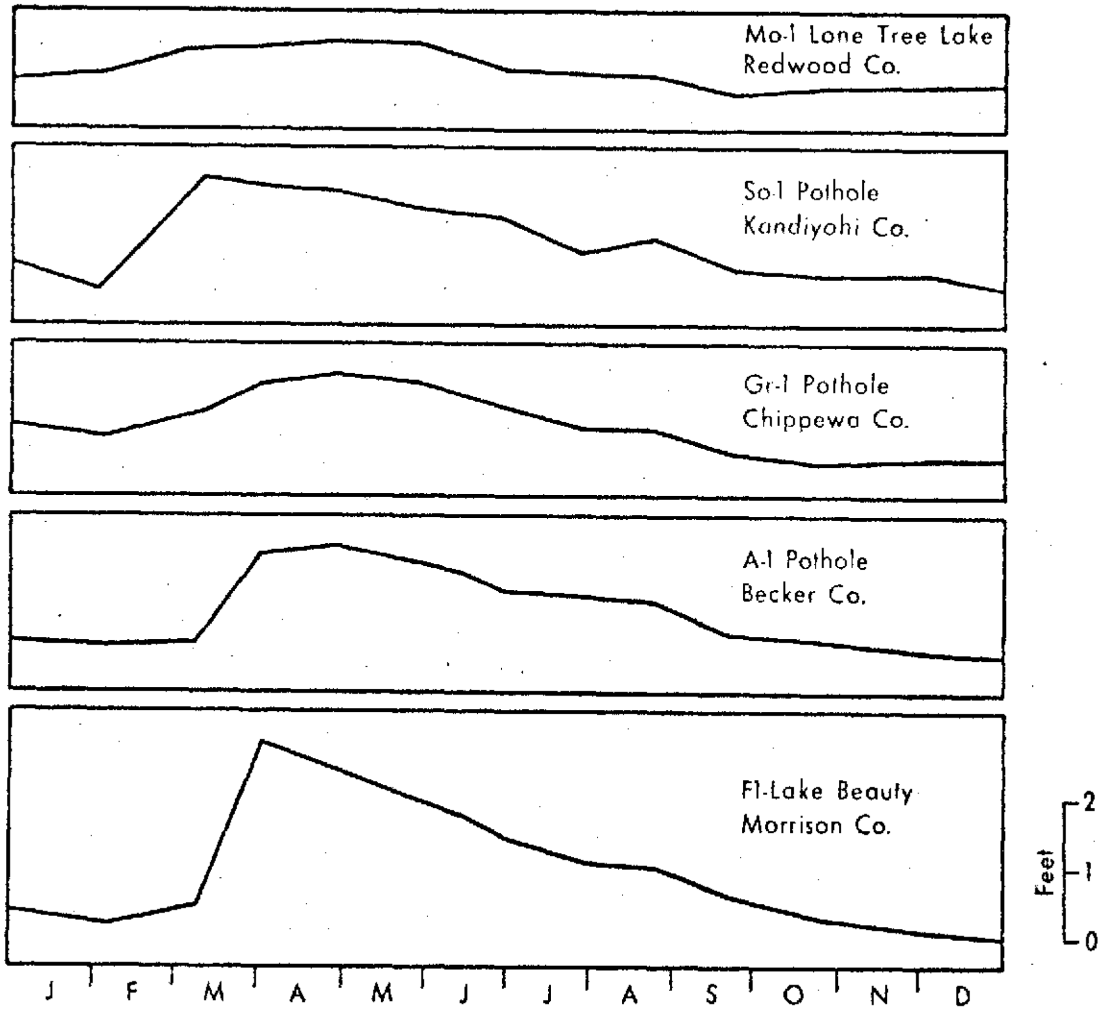


Fig. 11. Examples of vertical water level fluctuations of several potholes and lakes in 1966.

decline through the summer to levels in the autumn at or below those of the previous winter.

Fluctuations in surface area of ponds and lakes in the gently rolling landscape of Otrey Township should parallel the vertical fluctuations observed above. Since measurement of surface area of relatively large water bodies is virtually impossible without resorting to some form of remotely sensed image, such investigations are rarely attempted. The costs of repeated aerial overflights of an area to obtain an annual cycle of coverage have been prohibitive. Repetitive coverage by satellite images overcomes such barriers.

An Annual Fluctuation Regimen from ERTS-I.

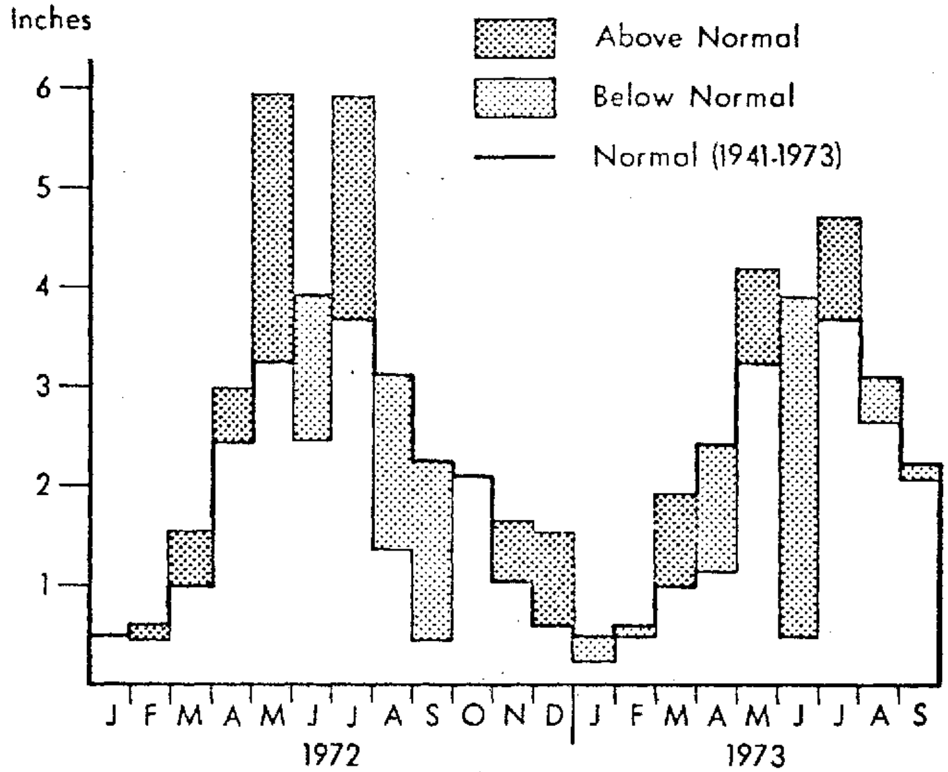
The concept of variability is of overriding importance in understanding the climate of West-Central Minnesota. It is an area marked by frequent and extreme fluctuations in all factors that interact to produce climate. The landscape in many ways reflects this variability. Lakes and ponds, in particular, are closely linked to changing weather conditions, since their numbers and size are very dependent on precipitation and evaporation conditions. Under such conditions, "normal" or "average" constructs can be used only as comparative bases from which to analyze deviations. A year of weather information seldom corresponds very well to a computed normal year. This section will describe how fluctuations in numbers and acreages of water areas detected from ERTS imagery for a one year period from August, 1972 to July, 1973 reflect changes in weather conditions for the same period.

As with nearly any other one year period of record, weather conditions during the year encompassed by this study varied considerably from normal (Fig. 12). Although precipitation in June of 1972 was somewhat below normal, the spring and most of the summer were very wet. These wet conditions were followed by two months of dryer than normal conditions in August and September. ERTS images should show water area contractions for this period since temperatures were about normal. Autumn and early winter of 1972 was a period of above normal precipitation and below normal temperatures, but January and February were unusually warm and snowless. Temperatures in the spring of 1973 were near normal and precipitation was slightly higher than usual, which should be reflected in ERTS data as a fairly abrupt increase in water acreage in the spring. However, June was a month of normal temperatures and almost no rainfall, so ERTS data should show a rapid decline in water area numbers and acreage for the month. The return of above normal rainfall in July should result in at least a slowing of the rate of water contraction of the previous month. The foregoing interpretation of the weather record compares favorably with observations expressed by the area game manager for the DNR:[34]

> The spring and early summer of 1972 was very wet in Big Stone County. As a result of this, many farmers were unuable to plant all their crops. Wet conditions also delayed harvest in the fall. December of 1972 was quite cold and had quite a bit of snow. It looked like it was going to be a very tough winter. However, January and February were unusually mild and the winter proved to be very mild. There was not a great deal of runoff in the spring of 1973. As a result there was very little if any water in the Type I water areas. However, in contrast to this, the lakes and large marshes were at their highest levels. As a result of this high water, some marshes lost their emergent vegetation. The season

---

[34]Personnal correspondence with John A. Scharf, Area Game Manager with the DNR in Morris, dated Nov. 29, 1973.



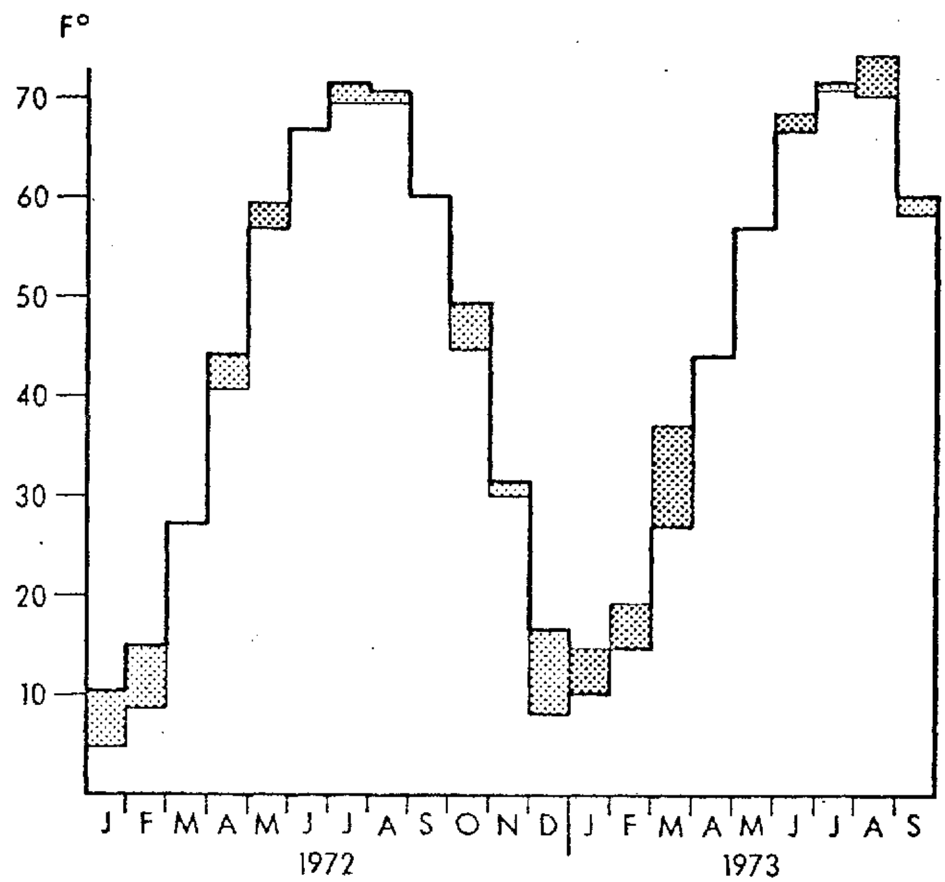


Fig. 12. Total monthly precipitation and mean monthly temperature at Artichoke in 1972 and 1973.

during the summer of 1973 was excellent in this general area, with moisture coming at the right time. It was a year of very good crops.

If, as postulated, lakes and ponds in the study area fluctuate in size and number in direct response to seasonal weather changes, and interpretation of water from ERTS satellite images is as accurate as the analysis of the preceding chapter indicates, four trends should be observable in the ERTS interpretation data: (1) a contraction of water areas in late summer leading to stabilization in the autumn, (2) a normal abrupt expansion in the spring, (3) a sharp contraction in June, and (4) a slowing of the rate of contraction in July. Of course allowance must be made for the limited number of observation dates. It is also assumed that actual fluctuations in the water resource are of a magnitude sufficient to override inherent inconsistencies in interpretation methodology and image quality.

As was demonstrated in the preceding chapter, interpretation from ERTS images produced great variations in the shape and sizes of lakes in Brandon Township. Such variations were also present in the lakes of Otrey Township. Examination of the one year fluctuations of individual lakes is quite confusing and gives only a vague impression of general trends. However, by grouping lakes into size classes and computing a cumulative aggregation of their numbers and acreages, general trends become much clearer (Figs. 13 and 14).

A comparison of these trends with the four that were expected from examination of the climatic record reveals that three occurred as expected, and one did not. Instead of an expected

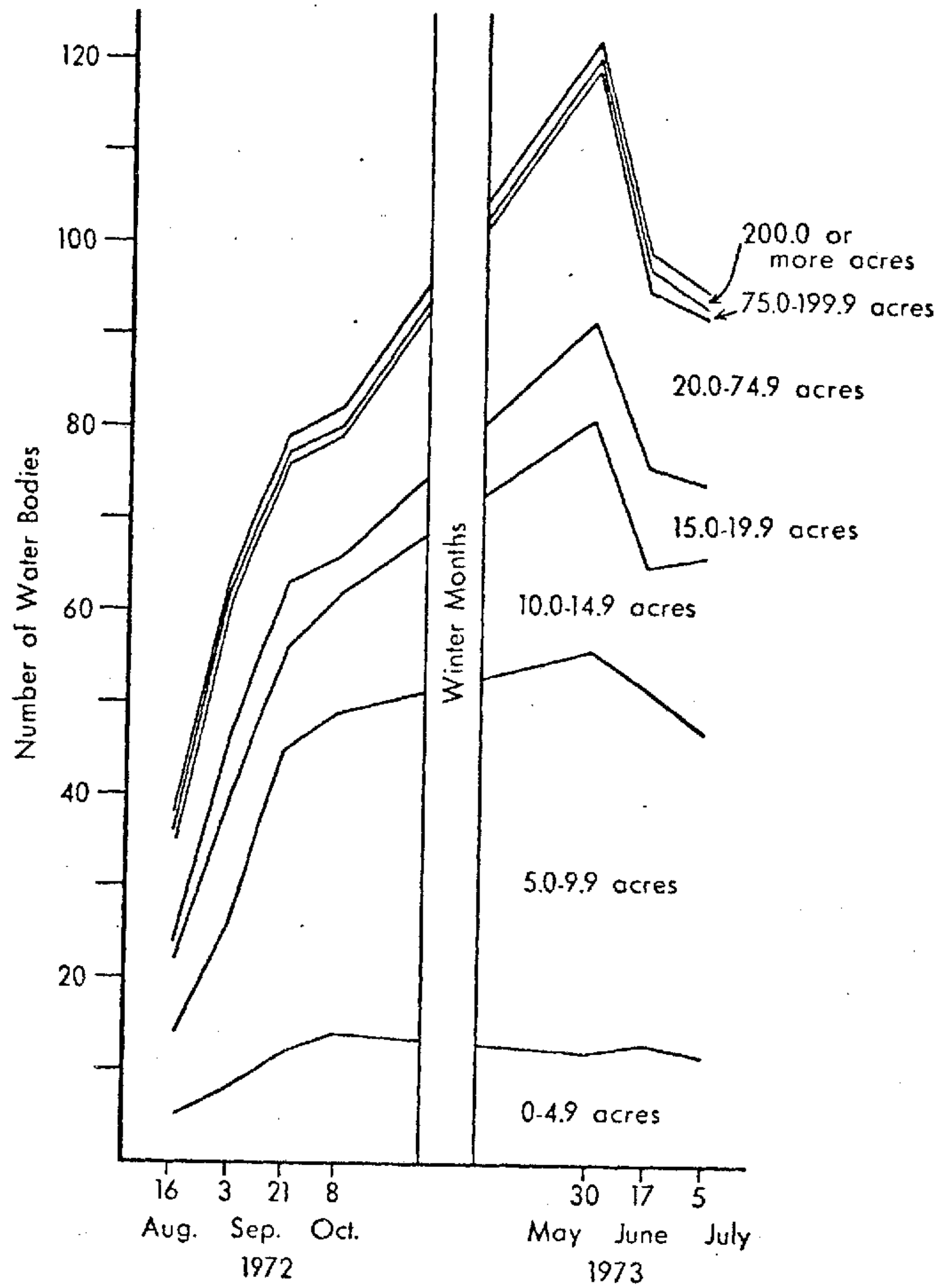


Fig. 13. Cumulative number of water areas (by size class) detected from ERTS: Otrey Township.

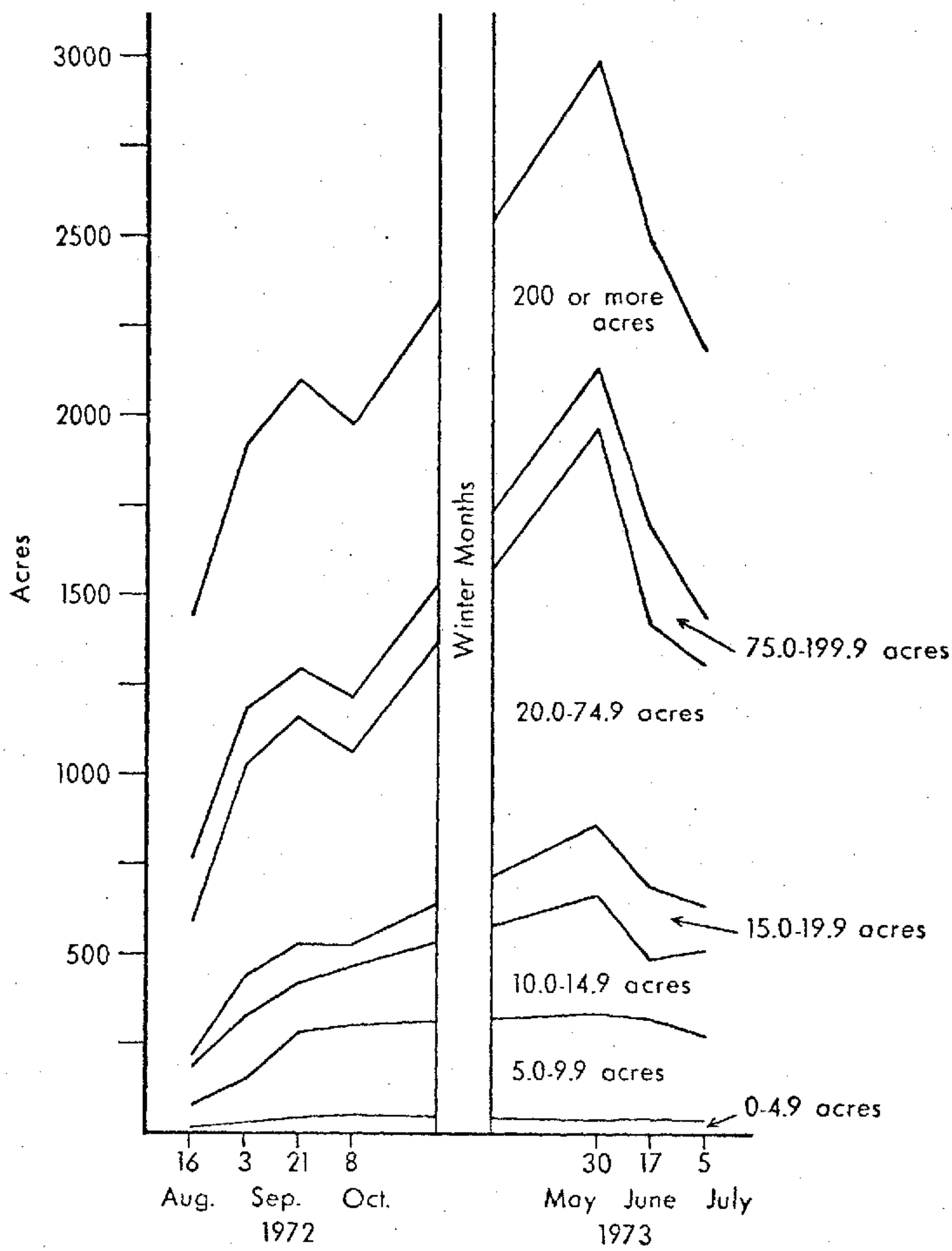


Fig. 14. Cumulative acreage of water areas (by size class) detected from ERTS: Otrey Township.

decline in water areas from August through September in response to below normal precipitation and normally warm temperatures, both numbers of water areas and acreages showed dramatic expansion. One can only speculate as to the cause of this anomolous situation, but there are several possibilities. The summer of 1972 was very wet, which may have caused water levels to reach heights sufficient to kill stands of emergent vegetation. The preceding four years all had above normal precipitation, which may have raised the local water table enough to affect lake levels. But this would have had a stabilizing influence rather than the expansion observed in the data. Perhaps the most plausible explanation has to do with image quality. Images for this period were some of the first to be produced by the NASA-ERTS system. As with any new system of production, there was undoubtedly an initial period of adjustment and refinement before consistently high quality output could be produced. Improvement of image quality is very evident in color-combined images received after the interpretation for this study had been completed. It is probably safe to assume such improvements also occurred in the initial production of 70mm images.

In contrast with the unexpected results for the late summer of 1972, ERTS data for the spring and summer of 1973 conformed very well to expectations. The normally expected water area expansion of early spring is documented by May 30 data, but the peak may have occurred earlier, since spring came early in 1973. The mean monthly temperature in March was considerably above normal and was followed by normal mean temperatures in subsequent months.

As expected, the lack of precipitation in June produced a sharp decline in the numbers and acreage of water areas. The contraction was slowed by arrival of above normal precipitation in July.

The fluctuation graphs also reveal how various size classes of lakes and ponds respond to varying amounts of precipitation. In the study area, small and medium size water areas (up to seventy-five acres) account for an overwhelming proportion of the number of water areas. But the bulk of water acreage is contained in areas over twenty acres. When precipitation and runoff are at a maximum and evaporation is low in the spring (May 30), the smaller water areas (under twenty acres) account for a large share of the increase in water area numbers. As contraction conditions develop in mid-summer, the smaller areas also show the most dramatic decline in numbers. In terms of change in water acreage over large areas, however, the small water areas are relatively insignificant. Most of the fluctuation in water acreage occurs in areas over twenty acres in size.

Analysis of ERTS interpretation in Brandon Township revealed considerable interpretation errors for some imagery dates. Since Otrey Township is even more agricultural and has darker soils than Brandon, considerable errors of comission were expected. Indeed, some errors were made, but analysis of them in a manner identical to that used in Brandon (except 1968 photographs were used in Otrey) revealed the problem to be relatively minor. All errors were on areas less than twenty-one acres (Table 6), and acreages involved were minimal. For the date with the most errors, May 30,

TABLE 6.--NUMBER AND ACREAGE OF MISINTERPRETED AREAS: OTREY TOWNSHIP

Image Date		Size Classes (acres)								
		0-4.9	5.0-9.9	10.0-14.9	15.0-19.9	20.0-74.9	75.0-199.9	200.0+	Total	Total Misinterpreted as % of Total Interpreted
16 Aug. '72	Numbers	1	-	-	-	-	-	-	1	2.6
	Acres	3.8	-	-	-	-	-	-	3.8	.3
16 Aug. '72 Color	Numbers	-	-	-	-	1	-	-	1	1.7
	Acres	-	-	-	-	20.5	-	-	20.5	1.2
3 Sep. '72	Numbers	-	1	2	-	-	-	-	3	4.7
	Acres	-	6.4	25.0	-	-	-	-	31.4	1.6
21 Sep. '72	Numbers	3	9	2	1	-	-	-	15	1.9
	Acres	12.1	68.5	24.3	18.6	-	-	-	123.5	5.9
8 Oct. '72	Numbers	5	3	-	-	-	-	-	8	9.8
	Acres	17.3	20.5	-	-	-	-	-	37.8	1.9
30 May '73	Numbers	6	8	4	1	-	-	-	19	15.6
	Acres	19.7	49.9	54.4	15.4	-	-	-	139.4	4.7
17 June '73	Numbers	3	3	-	-	-	-	-	6	6.1
	Acres	9.7	16.7	-	-	-	-	-	26.4	1.1
5 July '73	Numbers	5	5	1	1	-	-	-	12	12.6
	Acres	15.4	32.0	14.1	19.2	-	-	-	80.7	3.7
Total	Numbers	23	29	9	3	1	-	-	65	
	Acres	78.0	194.0	117.8	53.2	20.5	-	-	463.5	

Source: Interpretation of ERTS images by author.

the number of misinterpreted areas was about fifteen percent of the total number detected, but amounted to less than five percent of the total acreage detected. As in Brandon, most errors occurred on dates when the amount of plowed fields in the scene was at a maximum, 21 September and 30 May. Field investigation in the fall of 1973 confirmed that misinterpreted areas were cropland which presumably was plowed at the time they were imaged by ERTS (Figs. 15 and 16).

Detection of Marsh.

To this point, this study has focused on the detection, mapping, and measurement of open water areas from satellite imagery. But many basins in West-Central Minnesota contain little water. They are covered by "marsh" or "emergent" vegetation which thrives when water depths are consistently less than about three feet.[35] Emergent vegetation frequently forms a belt around areas of deeper, open water, and often completely covers basins. Such areas are very important as nesting cover for waterfowl, pheasants, and other birds. They provide habitat for furbearers in a landscape nearly devoid of wooded areas, and are very important for the survival of upland game birds during severe winter storms. As was briefly mentioned earlier, some preliminary attempts were made at detecting marsh on 70mm ERTS images, but the effort was abandoned. It was very difficult to distinguish marsh areas from areas of

[35]Ruttner, op. cit., footnote 25, p. 181.

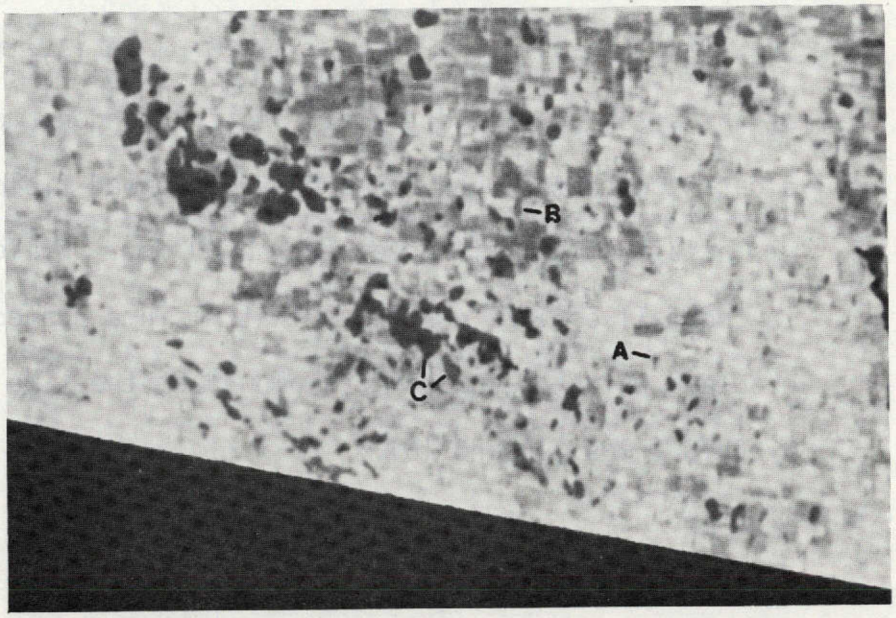


Fig. 15. Examples of plowed fields misinterpreted as water in Otrey Township from ERTS image 1311-16435-7 of 30 May '73.

Fig. 16. Ground photograph (taken in Nov., 1973) of a field in Otrey Township misinterpreted as water on ERTS image 1311-16435-7 of 30 May '73. Dark prairie soils of this field (B of Fig. 15) resembled open water.

cropland and pasture. However, as the study progressed some NASA-produced 9x9 inch color-composite images were received and an attempt was made to detect marshes on one of these. It was hoped the association of very wet ground or standing water with emergent vegetation would produce a distinctive signature when three bands were combined into a color image. Analysis of this interpretation effort requires an evaluation of available information sources.

Bulletin #25 is supposed to delineate all basins over ten acres capable of holding water. Since it identifies many completely dry basins, it should also include large marshy areas, which may be considered an intermediate stage between open water and dry land. In Otrey Township, Bulletin #25 is very deficient when compared to high altitude aerial photographs taken in 1968 (Table 7). The 1968 photographs may be considered to represent fairly normal conditions. Taken on May 8, they image conditions following above normal rainfall in April, but the preceding fall and winter were quite deficient in precipitation (Fig. 17). The above normal April rains probably only refilled basins to near normal levels after the drawdown of the previous summer and fall. When Bulletin #25 data are compared with water and marsh interpreted from the 1968 photographs, severe deficiencies are apparent. For size classes over ten acres, Bulletin #25 lists 34 basins covering 2531 acres. Combining water and marsh areas over ten acres interpreted from 1968 photographs reveals 84 areas covering 3350 acres. Bulletin #25 severely underestimates both the numbers and acreage of lakes and marshes in the study area. A more realistic evaluation of the accuracy of ERTS interpretation can be had by comparing it

TABLE 7.--NUMBER AND ACREAGE OF HYDROGRAPHIC FEATURES: OTREY TOWNSHIP

Source		Size Classes (acres)							
		0-4.9	5.0-9.9	10.0-14.9	15.0-19.9	20.0-74.9	75.0-199.9	200.0+	Total
Bulletin #25 Basins	Number	-	-	3	6	17	5	3	34
	Acres	-	-	38.0	102.0	669.0	472.0	1250.0	2531.0
'68 High Altitude-Water	Number	7	7	9	5	12	1	2	43
	Acres	23.2	52.2	117.6	83.6	634.9	180.8	888.4	1980.7
ERTS Inventory Water	Number	33	66	33	14	28	1	2	177
	Acres	112.9	443.7	405.3	245.2	693.9	166.4	764.3	2831.7
'68 High Altitude-Marsh	Number	50	30	21	9	23	2	-	135
	Acres	162.6	219.2	251.6	150.2	811.9	230.0	-	1825.5
ERTS-16 Aug. '72 Color-Marsh	Number	-	3	6	3	9	-	-	21
	Acres	-	21.8	70.4	37.1	325.1	-	-	454.4
ERTS-16 Aug. '72 Color-Water	Number	1	29	7	4	14	1	2	58
	Acres	4.5	219.4	86.3	71.0	534.0	165.1	686.7	1767.0
ERTS-16 Aug. '72 Band 7-Water	Number	5	9	8	2	11	1	2	38
	Acres	19.7	58.9	100.0	35.2	383.3	163.2	686.7	1447.0

Source: Each source is explained and documented in the text.

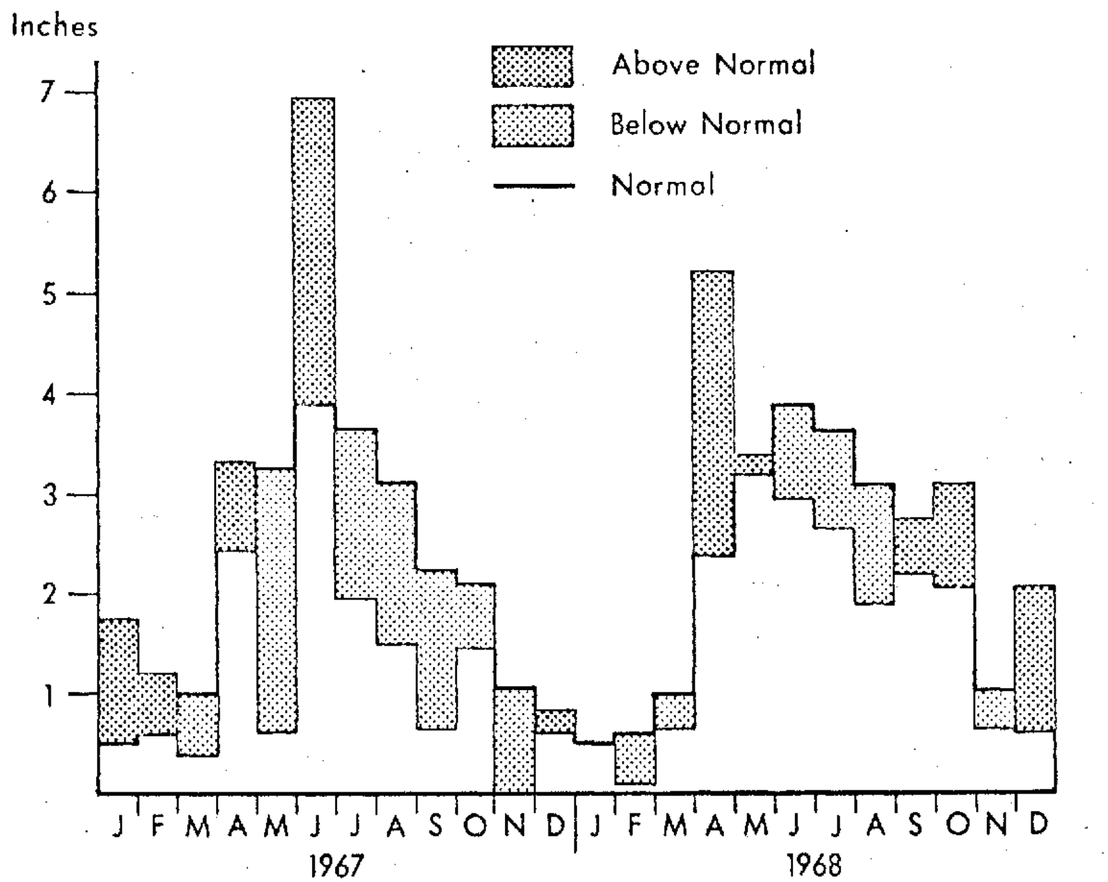


Fig. 17. Total monthly precipitation at Artichoke in 1967 and 1968.

with the 1968 photographs.

Such a comparison yields several interesting results (Table 7). Since, in the interpretation of the 1968 photographs, each basin was classified as either water or marsh, considerable areas of open water were designated as marsh and vice versa. This is readily apparent when the data are compared with water interpreted from ERTS. As stated earlier, preliminary investigation of band 7, bulk 70mm images indicated detection of marsh would be very difficult. An "either marsh or water" decision could not be made from ERTS, and all open water areas were mapped as water even though particular areas were small portions of large, marshy basins. About four times as many water areas were detected from ERTS as from the 1968 photographs, and almost fifty percent more acreage. Acreages of large water areas (greater than seventy-five acres) were approximately equal, with the ERTS acreages being slightly smaller. The disparity occurs in the small size classes under seventy-five acres. ERTS interpretation detected many small areas of open water in portions of large marshes.

Arrival of early NASA-produced color images enabled another attempt to be made at detecting marshes. The results are disappointing (Table 7). Only a few large marshes were detected, representing only about fifteen percent of the number and twenty-seven percent of the acreage of marsh interpreted from the 1968 photographs.

Color images may, however, facilitate detection of small areas of open water. A comaprison of detection of water from the color image with data from band 7 of the same 16 August image indicates the color image is superior (Table 7). Twenty more water areas were detected, covering an additional 200 acres.

The Cost of Data Acquisition.

A major factor influencing whether or not remotely sensed imagery is utilized as a tool in managing natural resources is its cost. This includes both the initial expense of acquiring suitable imagery and the cost of extracting data from it. Trade-offs between data quality and cost may make some types of imagery more attractive than others, though it may lack comparable properties such as fine resolution.

Throughout the course of data acquisition for this study, an attempt was made to record the amount of time spent on specific procedures (Tables 8 and 9). In addition to the procedures designated in the tables, a small amount of time was spent preparing base maps. This amounted to .10 hours/image in Otrey (the western border of Big Stone County is very irregular). Interpretation times for ERTS images include approximately .25 hours/image spent setting up the projection equipment and obtaining scale and focus. Most of this could be eliminated if the equipment could remain set up between periods of interpretation. Procedure times for the 1968 and 1969 high altitude photographs are included for reference, but are not directly comparable, since both marsh and water were interpreted from them, while only water was interpreted from ERTS images. It should also be noted that greater numbers of areas were mapped from the high altitude photographs, due to their

TABLE 8.--DATA ACQUISITION COST: BRANDON TOWNSHIP[a]

Image Type and Date	Procedure				
	Interpretation	Tracing	Numbering	Area Measurement	Total
'69 High Altitude	2.10	.75	.70	4.25	7.80
ERTS					
8 Oct. '72	.37	.25	.40	1.17	2.29
30 May '73	.50	.40	.25	1.00	2.25
17 June '73	.40	.37	.25	.83	1.95
5 July '73	.37	.25	.17	1.37	2.26
ERTS Average	.41	.32	.27	1.09	2.19

TABLE 9.--DATA ACQUISITION COST: OTREY TOWNSHIP[a]

Image Type and Date	Procedure				
	Interpretation	Tracing	Numbering	Area Measurement	Total
'68 High Altitude	1.50	.50	1.25	3.37	6.62
ERTS					
16 Aug. '72	.42	.10	.37	.50	1.64
3 Sept. '72	.50	.25	.37	.83	2.20
21 Sept. '72	.50	.25	.25	.85	2.10
8 Oct. '72	.45	.25	.25	1.00	2.20
30 May '73	.58	.25	.75	1.10	2.93
17 June '73	.50	.20	.70	.67	2.32
5 July '73	.50	.25	.25	1.10	2.35
ERTS Average	.49	.22	.42	.86	2.25

[a]All data for Tables 8 and 9 are in man-hours.

Source: Interpretation of high altitude aerial photographs and ERTS images by author.

finer resolution.

Interpretation alone averages less than half an hour per township and image data for both Brandon and Otrey. Estimating areas required three steps: tracing onto grid paper, numbering each area, and viewing through a microscope on a light table. These steps accounted for an additional 1.7 hours per township and image date, giving a total of about 2.2 hours for all procedures. This compares with between 6.5 and 8 hours per township from the high altitude photographs.

Since interpretation times were felt to be somewhat high because of inclusion of setup time, an attempt was made to arrive at a more representative estimate. All of the twenty townships in Douglas County were interpreted for water twice and the eleven townships in Big Stone County were done for one image date. Interpretation times averaged .125 hours per township in Douglas County and .18 in Big Stone. Open water can be interpreted very rapidly using the procedures described in this study. This conclusion is especially significant in today's climate of high wage rates. Bulletin #25, the closest facsimile to an inventory of Minnesota's waters currently available, took over a decade to complete.

The other major expense involved in using remote sensing for resource management is the initial cost of imagery. Low altitude aircraft coverage of a state the size of Minnesota would be extremely expensive. Complete coverage for a single year has never been flown. The only complete coverage of the entire state with high altitude aerial photographs (those used in this study) cost approximately $118,000. Complete coverage with ERTS images would involve between twenty-five and thirty images at a cost of $2.50 each, bringing the total cost of imagery to less than $100.

CHAPTER V. CONCLUSIONS AND IMPLICATIONS

West-Central Minnesota is an area that has been greatly altered through the process of European settlement. Once a rolling prairie landscape of grasslands, marshes, ponds, and lakes, the region has been transformed into one of the most productive agricultural areas of the state. Grasslands were the first component of the landscape to be drastically altered as they were put to the plow in the late 1800's. Originally, settlers either regarded the various water features indifferently or considered them favorable components of the landscape because of their value in providing wild hay to fuel the horse-drawn transportation network of the day.[35] But, by 1910, improvements in drainage technology and changes in agriculture (conversion from horses to tractors and development of better transportation links to markets) combined to make the conversion of wet areas to agricultural production economically attractive. In aggregate, the activities of settlement in the area have had profound effects on the land, flora, and fauna:[36]

> Development of agriculture, especially the intensified farming of recent decades, and other activities of man have adversely affected waterfowl use of many prairie wetlands. Row crops such as corn provide few nesting sites for ducks [or prairie chickens, grouse, and pheasants]. Thousands of the smaller water areas have

---

35Moline, op. cit., footnote 5, p. 244.

36John B. Moyle, ed., Ducks and Land Use in Minnesota, Technical Bulletin No. 8 (St. Paul: Minnesota Department of Natural Resources, Division of Game and Fish, Section of Research and Planning, 1964), p. 8.

> been drained to obtain more agricultural land and others have been filled or partly filled with silt eroded from adjacent lands. Water levels of lakes have been manipulated and the drainage patterns of some watersheds changed to allow better and faster agricultural drainage. In addition to changes brought about by agriculture, many shallow lakes have been damaged by German carp. Vegetation has been destroyed and waters made turbid.

Since the mid-1950's, attitudes toward lakes and wetlands have been shifting. An increasing proportion of the public is recognizing the ecological and aesthetic values of such areas and has been lobbying for their preservation. The Department of Interior's Bureau of Sport Fisheries and Wildlife (BSFW) and the Minnesota Department of Natural Resources (DNR) have each initiated programs to acquire fee title and easements to preserve wetlands threatened by drainage. They have also expended considerable effort on research programs and educational projects intended to provide the public with better information on the many values of wetlands and lakes. The BSFW has called for a shift in land use practices from row crops and small grains to grassland farming and other uses which sustain a permanent vegetation cover.[37] The State of Minnesota has adopted regulations which outline minimum standards for the use of shorelands of public waters over 25 acres.[38] Legislation has also been passed which broadly redefines "public waters" and "beneficial public use," and requires authorization by

---

[37]Waterfowl Production Habitat Losses Related to Agricultural Drainage: North Dakota, South Dakota and Minnesota--1954-1958 (Minneapolis: Bureau of Sport Fisheries and Wildlife, Branch of River Basin Studies, 1961), p. 15.

[38]Statewide Standards and Criteria for Management of Shoreland Areas of Minnesota, Minn. Reg. Cons. 70-77.

the DNR before initiation of any alteration activities such as drainage.[39] Such protective measures come at a time of increasing agricultural exports and rising prices for farm commodities--trends that are certain to increase pressures for more intensive cultivation techniques and expansion of cropland by drainage. Remote sensing technology is certain to play a role in the resolution of conflicts arising from these opposing land use ideologies. This study has focused on evaluating the feasibility of using relatively unsophisticated interpretation techniques on ERTS-I satellite imagery to obtain data presently needed by public agencies entrusted with responsibility for managing the water resources of the state.

Summary of Findings.

Perhaps the most important result of this study is the demonstration that unsophisticated, manual interpretation of primary satellite images (70mm bulk transparencies) can yield data on lakes and ponds better than existing information at a fraction of the cost of present acquisition procedures. Band 7, covering the .8 to 1.1 micron near-infrared portion of the spectrum, was judged the best single band for detecting and mapping open water. A scale of about 1:100,000 seemed to be the optimum for accurate mapping, but a slightly smaller scale of 1:126,720 was actually used because of the availability of adequate base maps in the form

---

[39]Minn. Stat. Chapt. 105, 106. (1974).

of half inch to the mile county highway maps. Interpretation of a color slide of a NASA-produced 9x9 inch color-composite image suggests that even better results can be obtained by using the multi-band color products. It may also be possible to somewhat enlarge the mapping scale. Color images received since the completion of the image interpretation phase of this study show marked improvements over earlier products and should provide interpretation results superior to those reported here.

Since no ground truth was available corresponding to specific ERTS overpasses, detailed analysis of individual images was not attempted. Rather, an inventory of open water was done by compiling water areas detected on four dates of ERTS images for Brandon Township in Douglas County. The results were then compared with other information sources which purport to represent normal water conditions. Although some water areas of less than five acres were mapped, many were missed, and numerous freshly plowed fields were misinterpreted as small water areas in autumn and early spring. By mapping only water areas larger than ten acres and/or avoiding images taken during periods when plowed fields lack a vegetative cover much of this trouble could be alleviated. Of course in non-agricultural areas of the state the problem would probably be insignificant.

Another conclusion which may be drawn from this investigation is that the accuracy of area estimations of water bodies decreases with decreasing size and increasing irregularity of shape. Since MSS images are composed of scan lines which contain numerous individual picture elements (pixels), exact placement of boundaries which cut through pixels is difficult. As the size of water areas decreases and the length of shoreline increases because of irregularities in shape, the proportion of the total area which is affected by this boundary effect increases, thus increasing the variability in border placement and area estimation. This problem is being effectively dealt with by investigators using computer algorithms to interpret digital tapes.[40] With the visual techniques used in this study, the problem can probably best be handled by averaging size estimates from multiple interpretations.

A final significant conclusion is that inconsistencies in the methodology used in this study are not of sufficient magnitude to obscure natural seasonal fluctuations of lakes and ponds. Investigation of seven image dates covering ice-free periods in a one year cycle in Otrey Township, Big Stone County revealed fluctuations in water area numbers and acreages which corresponded with observed weather patterns for the same period. One anamolous trend was encountered, but was probably related to the somewhat inferior quality of early images produced by the NASA-ERTS system. It may also be partially due to early unfamiliarity with interpretation procedures. Images for both Otrey and Brandon were interpreted in the sequence in which they were received. As image quality improved and interpretation procedures were mastered, more water areas were detected.

It should also be noted that fluctuations in individual water areas did not always correspond to seasonal weather trends. But

[40]Malila and Nalepka, op. cit., footnote 28.

when data on numerous lakes were aggregated, the resulting generalized trends were a good reflection of weather trends.

Initially, it was hoped that areas of emergent marsh vegetation could be detected from ERTS imagery, since such areas are an important component of the landscape of West-Central Minnesota. Preliminary investigation of individual spectral bands proved disappointing. An attempt was made to interpret marsh from a multi-band, color-composite image, with very limited success. The small areas of marsh vegetation so common in this part of the state cannot be adequately interpreted from ERTS imagery with the techniques used in this study. This is not particularly surprising. Other investigators employing four aerial cameras and a 17 channel multispectral scanner in an aircraft at 2000 feet had only limited success in recognizing aquatic vegetation associations in North Dakota.[41]

Possible Applications of Findings.

Perhaps the most valuable potential application of ERTS imagery in Minnesota is in an inventory of the water resources of the state. At present, the closest approximation of such an inventory is DNR Bulletin #25. But, as this study has demonstrated, Bulletin #25 has serious shortcomings. The most serious problem is that it identifies basins rather than water. This is probably

---

[41]Harvey K. Nelson, A. T. Klett, and W. G. Burge, "Monitoring Migratory Bird Habitat by Remote Sensing Methods," Transactions of the Thirty-Fifth North American Wildlife and Natural Resources Conference, pp. 73-83.

because those compiling the inventory had to rely on a variety of sources, including low altitude aerial photographs taken over a span of nearly twenty years. Too often, resource managers have used the data in Bulletin #25 to compute such indices as "crowding potential" (defined as a ratio of water acres to miles of shore) when, in fact, some of the water acreage may be dry land, and some of the miles of shore may not at present be shore.[42] This study has also shown that many small water areas were missed in the Bulletin #25 inventory, while some completely dry areas were included. The imagery and techniques described in this investigation would enable an improved inventory of water areas over ten acres to be completed in a matter of months at a fraction of the cost of the original survey, which took approximately a decade to complete. It might even be feasible to do several imventories representing normal, wet, and dry conditions. If an ERTS II satellite is orbited as planned, it should be possible to periodically update the inventory and monitor changes in surface water conditions on a state-wide basis.

This investigation has also demonstrated that the mapping of open water on USGS topographic sheets could be markedly improved by incorporating information derived from satellite imagery. At present, at least in the part of the state investigated here, USGS tends to underestimate open water areas in favor of overrepresentation of marsh. Perhaps the water inventory suggested above could be used by USGS in their mapping efforts.

---

[42]John R. Borchert, et. al., Minnesota's Lakeshore, Part II: Statistical Summary (Minneapolis: University of Minnesota, Center for Urban and Regional Affairs, 1970), p. 5.

Considering the state-wide coverage of county highway maps and the varied uses to which they are put, it might also be useful to improve the water portrayed on them. As this study has indicated, the water on present maps is neither very accurate nor consistent. It may not be necessary to map areas as small as ten acres, since in many parts of the state this would unduly clutter the map and obscure other information, but accurate portrayal of larger water areas (perhaps over thirty or forty acres) would improve the usefulness of all other information on the maps.

After obtaining a good inventory of average water conditions, resource managers are next interested in change. There is a major interest in being able, for example, to monitor man-induced changes in water areas such as lake level control activities and drainage. Recent state laws (cited earlier in this chapter) require permits from the DNR before altering public waters in any fashion. Periodic monitoring by satellite may provide a means of enforcing such regulations for water areas within the detection capabilities outlined in this study. For instance, drastic changes in size, shape, and number of water areas which do not correspond with observed weather trends may indicate alteration by humans.

Natural fluctuations in water conditions are also of great interest to resource managers. In periods of prolonged drought, such as much of the decade of the 1930's, lakes and ponds may completely dry up. Contraction of surface water areas may intensify water pollution and supply problems in some areas, affect availability of recreation resources in other areas, and adversely affect wildlife populations in still others. A recent study of lakeshore development in Minnesota outlined three types of problems which may accompany long periods of low precipitation:[43]

> (1) Desirable shoreline at current high water levels often ceases to be shoreline or changes from sand beach to swampy beach when water levels are low. (2) Decreased surface area when lake levels are low leaves [less] space for the same number of potential users. (3) Seasonal homes, if built on lake bottoms when water levels are low, can become flooded during periods of above-average rainfall. These flooded cabins represent an obvious public health hazard, are aesthetically displeasing, and might well be trespassing on state land.

Since drought conditions are not uniformly distributed over large regions, any up-to-date information on varying water conditions in different areas would be very useful to resource managers attempting to deal with such problems. This study has demonstrated that information of this sort can be quickly and cheaply acquired from satellite imagery.

Even shorter periods of deficient precipitation on the order of a year or two can have significant impact. For instance, extensive studies in South Dakota have revealed a strong correlation between the number of depressions holding water in an area and the use of the area by waterfowl for reproduction.[44] Another study, covering the entire United States, found a "...direct relation between the distribution and abundance of shallow and deep inland fresh marshes

---

[43]John R. Borchert, et. al., Minnesota's Lakeshore, Part I: Resources, Development, Policy Needs (Minneapolis: University of Minnesota, Center for Urban and Regional Affairs, 1970), p. 7.

[44]Charles D. Evans and Kenneth E. Black, Duck Production Studies on the Prairie Potholes of South Dakota, Special Scientific Report--Wildlife, No. 32 (Minneapolis: U. S. Department of the Interior, Fish and Wildlife Service, 1956).

(Types 3 and 4) and the distribution and abundance of young ducks produced in the United States."[45] State and federal agencies have responded to this relationship by conducting several sampling inventories of existing wetlands to help develop acquisition priorities and, since 1947, have conducted aerial surveys of habitat and waterfowl numbers each year to aid in establishment of hunting regulations. At present the model used for predicting annual production of young mallards directly incorporates estimates of ponds existing in May and July.[46] Since many of the water areas important to waterfowl are quite small, the detection limits inherent in the methods used in this study may restrict applicability to the larger wetlands. But if good relationships between the number of small wetland areas containing water and the size of selected large wetland areas can be established, perhaps satellite monitoring of large wetlands could serve as an early indicator of changing conditions.

---

[45]S. P. Shaw and C. G. Fredine, Wetlands of the United States: Their Extent and Their Value to Waterfowl and Other Wildlife, U. S. Department of the Interior, Fish and Wildlife Service Circular 39 (Washington D. C.: Government Printing Office, 1956), p. 27.

[46]Geis, et. al., op. cit., footnote 11.

SOURCES CITED

Allred, E. R.; Manson, P. W.; Schwartz, G. M.; Golany, Pinhas; and Reinke, J. W. Continuation of Studies on the Hydrology of Ponds and Small Lakes. Technical Bulletin No. 274. St. Paul: University of Minnesota. Agriculture Experiment Station, 1971.

An Inventory of Minnesota Lakes. Bulletin No. 25. St. Paul: Minnesota Department of Natural Resources. Division of Waters, Soils, and Minerals, 1968.

Beaman, W. M. Topographic Instructions of the United States Geological Survey. Washington, D. C.: U. S. Government Printing Office, 1928.

Borchert, John R.; Orning, George W.; Stinchfield, Joseph; Pederson, Donna; and Maki, Les. Minnesota's Lakeshore, Part I: Resources, Development, Policy Needs. Minneapolis: University of Minnesota. Center for Urban and Regional Affairs, 1970.

Borchert, John R.; Orning, George W.; Stinchfield, Joseph; Pederson, Donna; and Maki, Les. Minnesota's Lakeshore, Part II: Statistical Summary. Minneapolis: University of Minnesota. Center for Urban and Regional Affairs, 1970.

Colvocoresses, Alden P. and McEwen, Robert B. "EROS Cartographic Progress." Photogrammetric Engineering, American Society of Photogrammetry, Vol. 39 (1973), No. 12, pp. 1303-1309.

Cotter, R. D.; Bidwell, L. E. Oakes, E. L.; and Hollenstein, G. H. Water Resources of the Big Stone Lake Watershed. U. S. Geological Survey. Hydrologic Investigation Atlas HA-213. Washington, D. C.: U. S. Government Printing Office, 1966.

Data Users Handbook. Greenbelt, Maryland: National Aeronautics and Space Administration, 1972.

Evans, Charles D. and Black, Kenneth E. Duck Production Studies on the Prairie Potholes of South Dakota. Special Scientific Report--Wildlife, No. 32. Minneapolis: U. S. Department of the Interior. Fish and Wildlife Service, 1956.

Geis, A. D.; Martinson, R. K.; and Anderson, D. R. "Establishing Hunting Regulations and Allowable Harvest of Mallards in the United States." Journal of Wildlife Management, Vol. 33 (1969), pp. 848-859.

Goldstein, Jon. _Competition for Wetlands in the Midwest: An Economic Analysis_. Washington, D. C.: Resources for the Future, 1971.

Hewes, Leslie. "The Northern Wet Prairie of the United States: Nature, Sources of Information and Extent." _Annals_, Association of American Geographers, Vol. 41 (1951), pp. 307-323.

Larson, Gerald W. _Biological Survey of the West Branch of the Chippewa River, Pope, Stevens, Swift, Douglas, Grant, and Ottertail Counties_. Special Publication No. 49. St. Paul: Minnesota Department of Natural Resources. Division of Game and Fish. Technical Services Section, 1967.

Malila, William A. and Nalepka, Richard F. "Advanced Processing and Information Extraction Techniques Applied to ERTS-I MSS Data." Paper presented at the Third ERTS Symposium, Washington, D. C., Dec. 10-14, 1973. (Photocopied).

Mann, Grady E. "Improved Techniques for Aerial Wetland Surveys." _Journal of Wildlife Management_, Vol. 28 (1964), pp. 575-580.

Manson, P. W.; Schwartz, G. M.; and Allred, E. R. _Some Aspects of the Hydrology of Ponds and Small Lakes_. Technical Bulletin No. 257. St. Paul: University of Minnesota. Agriculture Experiment Station, 1968.

Marschner, F. J. _Original Forests of Minnesota_, (Map). Washington, D. C.: U. S. Department of Agriculture, 1930.
The original map has been lost, but two copies are on file at the North Central Forest Experiment Station, St. Paul, Minnesota.

Minn. Stat. Chapt. 105, 106 (1974).

Minnesota Wetlands, (Map). St. Paul: Minnesota Department of Natural Resources. Division of Game and Fish. Section of Game, 1973.

Moline, Robert T. "The Modification of the Wet Prairie in Southern Minnesota." Unpublished Ph. D. dissertation, University of Minnesota, 1969.

Moyle, John B., ed., _Ducks and Land Use in Minnesota_. Technical Bulletin No. 8. St. Paul: Minnesota Department of Natural Resources, Division of Game and Fish. Section of Research and Planning, 1964.

Nelson, Elmer R. "Snowmelt Floods in the Red River of the North, Upper Mississippi, and Missouri Basins." Climatological Data, National Summary, Environmental Science Services Administration, Vol. 20 (1969), No. 4, pp. 197-201.

Nelson, Harvey K.; Klett, A. T.; and Burge, W. G. "Monitoring Migratory Bird Habitat by Remote Sensing Methods." Transactions of the Thirty-Fifth North American Wildlife and Natural Resources Conference, pp. 73-83.

Orning, George W.; and Maki, Les. Land Management Information in Northwest Minnesota: The Beginning of a Statewide System. Report No. 1. Minneapolis: University of Minnesota. Center for Urban and Regional Affairs. Minnesota Land Management Information System Study, 1972.

Personal correspondence dated Nov. 27, 1973 with Thomas F. Fischer, District Conservationist with the Soil Conservation Service in Alexandria, Minnesota.

Personal correspondence dated Nov. 29, 1973 with John A. Scharf, Area Game Manager with the Department of Natural Resources in Morris, Minnesota.

Personal interview on Feb. 7, 1974 with Thomas F. Follrath, Chief of Realty Branch, Bureau of Sport Fisheries and Wildlife, Minneapolis, Minnesota.

Ruttner, Frantz. Fundamentals of Limnology. 3rd ed. Toronto: University of Toronto Press, 1963.

Shaw, S. P. and Fredine, C. G. Wetlands of the United States: Their Extent and Their Value to Waterfowl and Other Wildlife. U. S. Department of the Interior, Fish and Wildlife Service. Circular 39. Washington, D. C.: Government Printing Office, 1956.

Statewide Standards and Criteria for Management of Shoreland Areas of Minnesota. Minn. Reg. Cons. 70-77.

Stinchfield, Joseph. "A Statistical Evaluation of the Minnesota Land Management Information Systems Land Use Study." Unpublished Master's thesis, University of Minnesota, 1972.

Waterfowl and Muskrat Habitat Survey of Otrey Lake--Big Stone Co. St. Paul: Minnesota Department of Conservation. Division of Game and Fish. Bureau of Wildlife Development, 1952. (Photocopied).

C-3

Waterfowl Production Habitat Losses Related to Agricultural Drainage: North Dakota, South Dakota and Minnesota--1954-1958. Minneapolis: Bureau of Sport Fisheries and Wildlife. Branch of River Basin Studies, 1961.

Wilson, John N. "The Limnology of Certain Prairie Lakes in Minnesota." _The American Midland Naturalist_, Vol. 59 (1958), pp. 418-437.

Work, Edgar A., Jr.; Gilmer, David S.; and Klett, A. T. "Utility of ERTS for Monitoring the Breeding Habitat of Migratory Waterfowl." Paper presented at the Third ERTS Symposium, Washington, D. C., Dec. 10-14, 1973. (Photocopied).

REMOTE SENSING IN LAKE SUPERIOR STUDIES

Investigator: Dr. Michael Sydor
Department of Physics
University of Minnesota, Duluth

TURBIDITY STUDIES

In our initial introduction of the results on ERTS uses in turbidity measurements, we have generally addressed ourselves to establishing the areas of high turbidity on Lake Superior and the degree of the turbidity, mainly for the purpose of producing a product for users, say in the cases of location of water intake or filtration of water. We have found, however, that in many cases ERTS data was quickly used to exemplify contentions that certain users had in presenting their case for a particular cause. For example, if a case was to be made against high water levels in Lake Superior, a sensitive issue, then the data on turbidity was used to demonstrate the erosion of red clay along the Wisconsin shore. On the other hand, in consideration of projects for the erosion control on the Nemadji River, the turbidity in the lake was blamed on the Nemadji River, etc. Now it is true that both are sources of turbidity, though by no means all of it, but the degree of contribution to lake turbidity due to each source cannot be left to the convenience of any particular political cause. It thus leaves us the task of, not only mapping out the turbidity as it is found on the lake for any month, but also that of determining where the turbidity comes from, i.e. the problem of effluent tracing. This is a difficult problem, and the geographical location of the turbid water is not necessarily a good clue to the answer. We are thus in the process of investigating the method of effluent identification. The ERTS computer data appears to hold the greatest promise for this, as we pointed out in the paper presented at the Ninth Symposium on Environmental Sensing at Ann Arbor by Stortz and Sydor. Laboratory experiments on light scatterings are a part of this project, and are of keen interest to our research program for the sake of curiosity, and graduate education of our students.

WATER TRANSPORT

The application of the ERTS/data to use in studies of currents is also progressing well. The support for that part of our program comes almost entirely now from other agencies. Some of the results will be presented (Maanum and Sydor) in a paper accepted by the Great Lakes Research Conference. The work is of particular use to the Corps of Engineers in their dredging disposal program.

WINTER STUDIES

Our investigation of Ice Growth in Duluth-Superior Harbor and the adjacent Lake Superior waters, and application of ERTS to studies of ice packing problem for 1972-73 shipping season was presented in the last report. The study has generated a great deal of interest from various agencies, such as NOAA, corps of Engineers, and the Department of Interior Geological Survey. The 1973-74 winter season has yielded beautiful ERTS data, which as yet we were not able to analyze fully; however, a report is being prepared on a related problem dealing with the extension of the winter navigation problems. A report, in a form of a paper should be forthcoming at the end of this year. Our difficulty here lies mostly in lack of manpower, and the time that we can devote to this aspect of our studies to write it up during the summer time. With the current emphasis on energy supply, and therefore shipping, this aspect of our studies may increase to become a dominant effort.

EDUCATIONAL PROGRAM IN REMOTE SENSING

With the purchase of data reduction facilities for remote sensing, we have a considerable investment in the field. It is only natural that the education on the use of remote sensing in various descriptions be introduced into the curriculum at the university, though it is already a part of the education of graduate students.

A preliminary introduction of the use of ERTS and application of remote sensing to various disciplines has come last academic year as a part of a new course in highlights in physics. The course had an enrollment of 115 students, coming from large varieties of academic disciplines. The topics were very well received, and the course will be continued next year.

We would, however, like to introduce a rigorous course at the sophomore level for majors in sciences, biology, geology, geography, urban studies, and forestry.

The course would consist of lecture material, mainly environmental application of optics, and a lab, which would introduce the students to techniques of remote sensing, and would require them to apply the technique applied to their particular discipline, particularly in the form of ERTS data used to produce diazo overlays. The students would have the task of getting their own ground truth data as part of their laboratory work. Basically, we would like to have this as a course offering in interdisciplinary studies as a part of the educational program of the Lake Superior Basin Studies Center at the University of Minnesota, Duluth, established by an act of the Minnesota Legislature in 1973.

Appendix A

REMOTE SENSING OF WESTERN LAKE SUPERIOR

Kirby Stortz and Michael Sydor

Lake Superior Basin Studies Center

University of Minnesota, Duluth

Duluth, Minnesota 55812

ABSTRACT

Correlation of ERTS data with measurements of turbidity and transmittance for water in the Duluth-Superior harbor and the adjacent Lake Superior water is used in production of turbidity maps for the extreme western arm of Lake Superior. Comparison of reflectance of water obtained from ERTS Bands 4, 5, and 6 as a function of suspended solids indicates the possibility of using this data in effluent tracing. Correlation of ground truth with satellite data allows for extension of results obtained from measurements at few key stations to a large area of the lake. The ability to do this is exceedingly important in the environmental studies of large bodies of water, where the dynamic nature of the system cost prohibits sufficient sampling measurements to cover the entire area.

INTRODUCTION

Study of water quality of the extreme western arm of Lake Superior is important because the Duluth-Superior area is the major source of pollution for the lake. The water in the extreme western arm is turbid in comparison to the rest of the lake, generally showing turbidities ten times higher than the remainder of the lake. Fig. 1 shows the area of the lake which is considered in this study.

The practical application of the measurement of the turbidity and its transport on the lake, pertains to the need for general knowledge of water quality available to the municipal water intake for the cities of Duluth, Superior, and Cloquet, and how the water quality is affected by natural and man-made sources of turbidity. The water taken from Lake Superior for municipal use is, as yet, not filtered. The Duluth intake, which is located along the north shore, does not often experience high turbidity problems. The Cloquet intake on the other hand, is usable only 50% of the time. Recent controversy with regard to the presence of asbestos-like fibers in the lake, dictates that all water should be filtered. The design of the filtration systems, and location of future intakes and the study of harbor effects due to shipping and dredging, all require the understanding of the water transport patterns and turbidity levels for various parts of the lake. Upwards of $8 million has been spent in the last five years on construction of inadequate water systems; a comparable amount will be spent in correcting the mistakes.

Several effects contribute to the water quality degradation; natural erosion of red clay banks (heightened by high lake levels), runoff, industrial and commercial activity in the harbor, and increased effluent from the cities. The study area encompasses 200 square miles of lake, thus measurements involving effluent tracing and turbidity levels need to be done on a gross scale. This coupled with the dynamic nature of plumes on the lake would require large scale sampling operations which would be cost prohibitive. Previous attempts to use turbidity for detection of surface currents through aerial photography did not prove useful.[1] It was therefore interesting to apply ERTS to the problem of turbidity mapping and effluent tracing. The first few images from ERTS showed striking patterns of turbidity on the lake, indicating high turbidity over the Cloquet intake and the southern shore area and displayed complex current patterns. It was evident from the start that the Cloquet water intake was located in one of the poorest possible locations.

Our first aim to use ERTS quantitatively was to correlate the suspended solids with the MSS signal intensity, both through the analysis of 70 mm bulk images and the computer compatible tapes. This was done in hope that we would be able to extend the results of measurements collected at few strategically located points determined from visual observation of past ERTS images to other areas of the lake.

EXPERIMENTAL

The basic need was to establish the correlation between suspended load and the image intensity, and to subsequently determine if ERTS data could be used to determine the origin of the effluent. The latter being of particular importance in tracing the harbor effluents, which are polluted.

The turbidity source along the southern shore is characterized by high suspended solids, mostly red clay suspended in otherwise clean Lake Superior water; while effluents from the harbor area contain moderate values of suspended solids from the St. Louis River mixed with red clay load from the Nemadji River (which becomes the dominant turbidity source from the harbor area during runoff time). The harbor water contains high dissolved solids and has a high light absorption coefficient. Since the transparency of the lake and the harbor water differ radically, it was possible that variation of reflectance in ERTS bands with suspended solids would differ enough for the two major turbidity sources, to allow for their distinction through color combining analysis. Subtle differences would not be sufficient in optical analysis of the data, the computer tapes could however prove fruitful. Since ERTS coverage of the western tip of the lake for consecutive days did occur, it was also hoped that a measure of the settling rates could be attempted by computation of average turbidity over the area for each day. In anticipation of these results, we had made during the past summer, measurements of turbidity, suspended solids, secchi disc, electrical conductivity, temperature and dissolved oxygen at several points on the lake and the harbor. The data was collected on 25 days from June 20 to November 6. Water transparency and surface and sub-surface currents were also measured. The measurements were taken at stations which were predetermined by examination of past ERTS images showing the areas of high turbidity concentration and the prevailing surface current patterns. Special emphasis was placed on measurements for the days of ERTS I overflights. For such days, two boats were used, allowing for measurements at an average of 12 stations on the lake. The satellite data was then correlated with the ground truth data to determine the possible use of ERTS in turbidity measurement and effluent tracing on Lake Superior.

RESULTS AND DISCUSSION

Figure 2 shows the correlation between turbidity and suspended solids measurements. The correlation is largely independent of the type of effluent since the absorption effects over short paths inherent in the turbidity meter are small. A linear least squares fit for 116 samples yields relationship

$$SS = 1.04*TB - .38$$

where suspended solids is measured in mg/l and turbidity is measured in FTU. The correlation coefficient for this data is .97. The turbidity measurement takes little time, and is therefore the most convenient parameter for correlation with the satellite data.

The relationship between turbidity and signal intensity in Band 5 is shown in Fig. 3. Similar graphs were also plotted for Bands 4 and 6. A linear least squares fit was applied to the data, with resulting correlation coefficients of .90, .96, and .91 for Bands 4, 5, and 6 respectively. Thus Band 5 is most useful in determining general turbidity from ERTS MSS data, since it appears to be least sensitive to the nature of the effluent. The slope of the line is nearly the same from day to day, however, the intensity of the signal does depend on the atmospheric condition.[2] Gross turbidity values can be obtained[3] without a calibration point, but for accurate turbidity analysis, at least one calibration point is required. Fig. 4 shows a typical turbidity map for the extreme western arm of Lake Superior produced by optical density slicing of a 70 mm bulk image taken in Band 5. Fig. 5 shows the same result obtained from the computer compatible tape.

The possibility of effluent tracing using ERTS depends on the difference in the relative response of Bands 4, 5, and 6 to a constant suspended load for different types of water. Since the response in each band is a function of the penetrability of light in water, we consider the transmission characteristics of the lake and harbor water shown in Fig. 6.

It is seen that Band 7 is not useful in turbidity studies because of high light absorption by water in that region. Images taken in this band are however useful for outlining of the water mass, and distinguishing very turbid water from exposed shores. The relative response for the harbor water is best in Band 6. Band 4 has the deepest penetration for the lake water, and as such is the most susceptible to the variation of suspended load with depth. The difference in the spectral reflectance of various effluents is shown in color images, such as those obtained from Skylab. Two types of events on the lake are prominent. One type is characterized by a period of relatively calm weather, which results in relatively low turbidity in the western arm of Lake Superior, ranging from 1 to 5 mg/l suspended solids. The turbidity patterns are faint, and difficult to interpret for the purpose of correlation with water currents. It is important for such events to determine whether the turbidity near the harbor entries comes from the harbor area or from old red clay plume. The differences in the signal intensity in various bands for different effluents are rather subtle at low concentrations and can only be differentiated on ERTS using the computer compatible tapes. The second type of event is typified by very large turbidities, often showing directly the origin of a turbid plume. However, since the red clay stays in suspension for a long time, turbid plumes are sometimes found in the middle of the extreme western arm of the lake, and could have originated either at the harbor entries or the south shore, as shown in the now famous image of August 12, 1972 (Fig. 7). Often during such times, the harbor effluent appears "clean" on the image as it enters the lake. For such highly turbid waters, it is necessary to determine the origin of the turbidity, for the purposes of establishing the area of influence of each turbidity source. This is a crucial question in the discussion of the harbor dredging problems, where it is necessary to trace the polluted effluents from the harbor. The turbidity plume in this case could serve as a natural tracer dye. To investigate the possibility of effluent tracing with ERTS, we consider Fig. 8, which shows the relative intensity for Bands 4, 5 and 6 for the harbor and red clay effluents for the two characteristic types of days. Recall that the curves for high suspended solids both pertain largely to the red clay. The Nemadji source is however mixed in with the harbor area water which shows poor penetrability in Band 4 and a relatively good response in Band 6.

The data shows that effluent type could be distinguished using the computer tape data for low turbidities. For high turbidities, color combining technique may also be feasible. Using this criterion in considering the plume off Minnesota point on August 12, 1972, the data shows that the plume originated from the Nemadji.

We have used the turbidity plumes to determine the general water transport patterns in the extreme western arm of Lake Superior, and to determine the range of turbidities occurring naturally in different areas of the lake. Further work concerning effluent tracing, depth of response, and settling rates is in progress. An estimate of the latter can be obtained for the western arm of Lake Superior for the days when ERTS images for two consecutive days are available. Data for two such occasions exists. The turbidities are too low, however, for satisfactory optical analysis of the images. We expect that the computer data will prove more useful. The depth of response, based on examination of the reflectivity for several turbidity profiles, indicates that the satellite data is applicable to surface turbidities within 80% of one secchi disc length. This for normal type of plume ranges from .5-3 meters in depth for Bands 4 and 5. The secchi disc transparency for clean water in western Lake Superior runs about 10 meters, well in excess of those depths.

The data is being applied to practical problems concerning dredging operations in the harbor. The dredgings were once disposed of in the lake, a practice which is likely to be resumed if the harbor area is cleaned up, and the limited on-land disposal area is exhausted. The on-land disposal methods are a factor of six more costly. Current estimates of the operation run in excess of $40 million for the next five years.

REFERENCES

1. T. Olson and T. Odlaug. Lake Superior Studies 1956-61. Minnesota Public School of Health.

2. P. Bennett and M. Sydor. Remote Sensing of Earth Resources Conference, Tullahoma, Tennessee, March 25-27, 1974.

3. J. Shertz, M. Sydor and J. Van Domelen. Third Annual Symposium, Washington, D.C., December 14, 1973.

FIGURE CAPTIONS

Fig. 1: Area of lake under study.

Fig. 2: Suspended solids and turbidity. Shows relationship for various kinds of lake water.

Fig. 3: Turbidity and signal intensity. Band 5 data is from computer tape.

Fig. 4: Turbidity map from optical data for Sept. 30, 1973.

Fig. 5: Turbidity map from computer tape data for Sept. 30, 1973.

Fig. 6: Transmission characteristics of lake and harbor water.

Fig. 7: Aug. 12, 1972, Band 5.

Fig. 8: Variation of band response with water type. Two common suspended solid levels are shown.

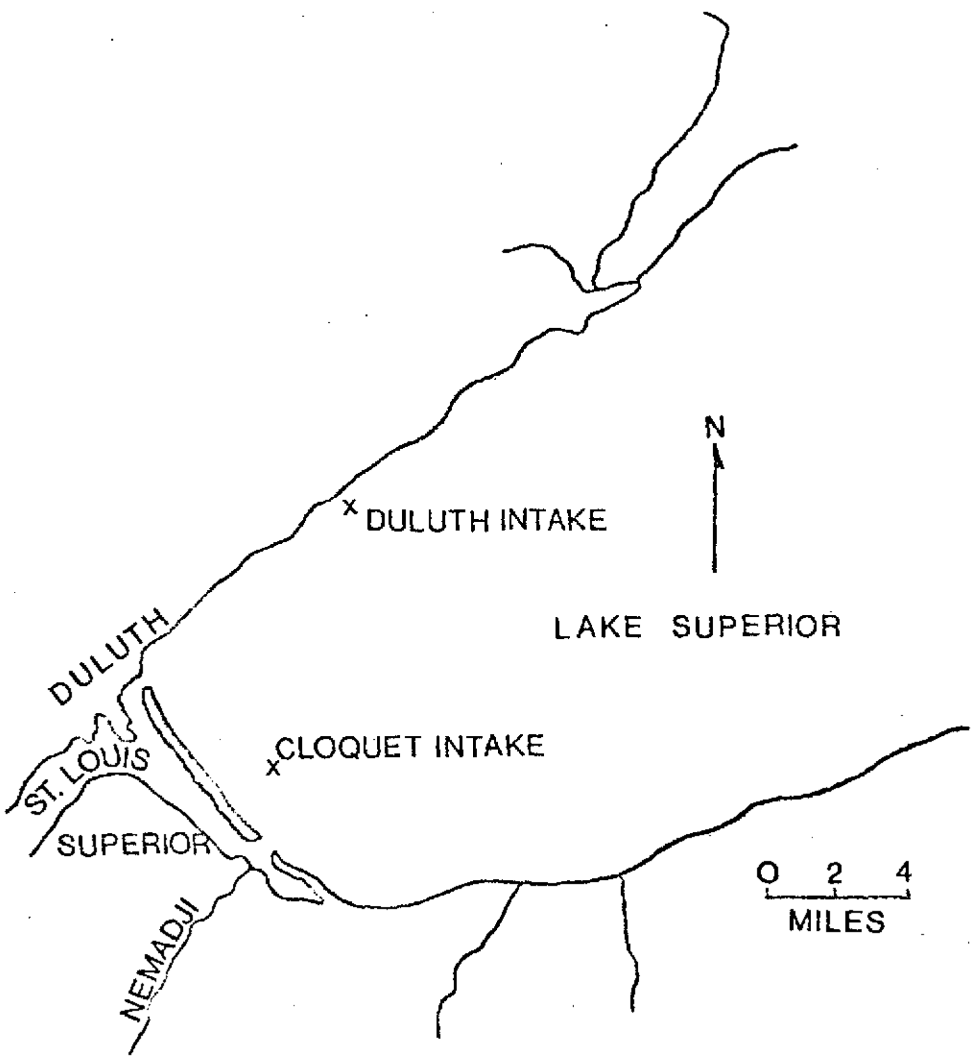

N
DULUTH INTAKE
LAKE SUPERIOR
DULUTH
ST. LOUIS
CLOQUET INTAKE
SUPERIOR
NEMADJI
0 2 4
MILES

Fig. 1

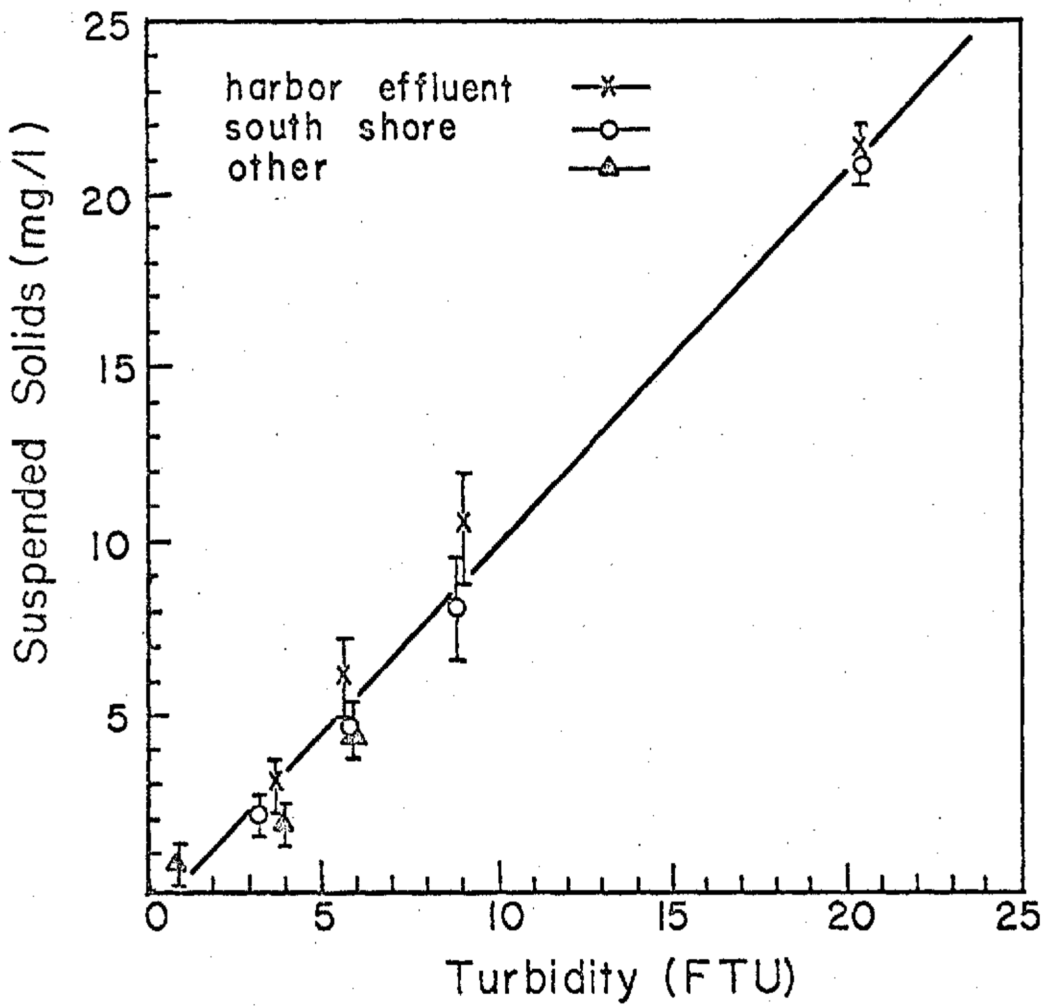

harbor effluent
south shore
other
Suspended Solids (mg/l)
Turbidity (FTU)
0
5
10
15
20
25

Fig. 2

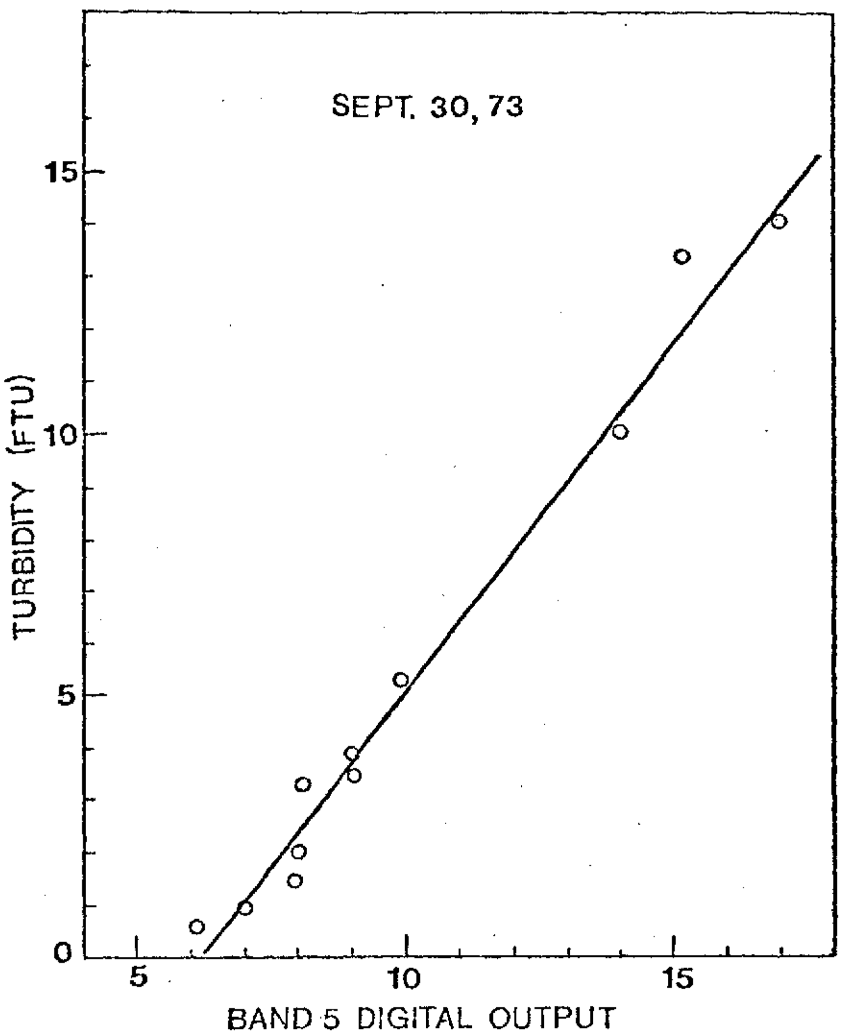
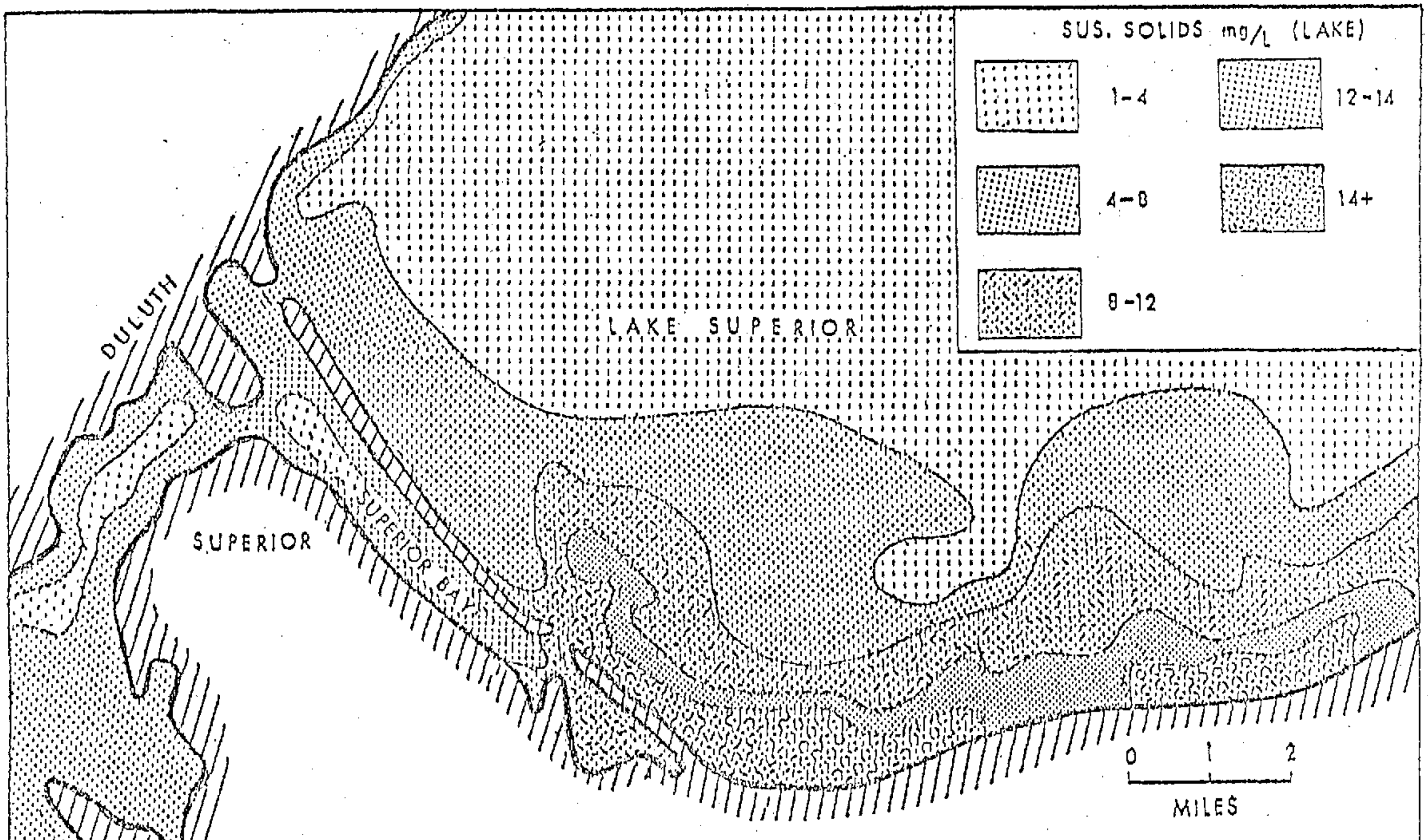


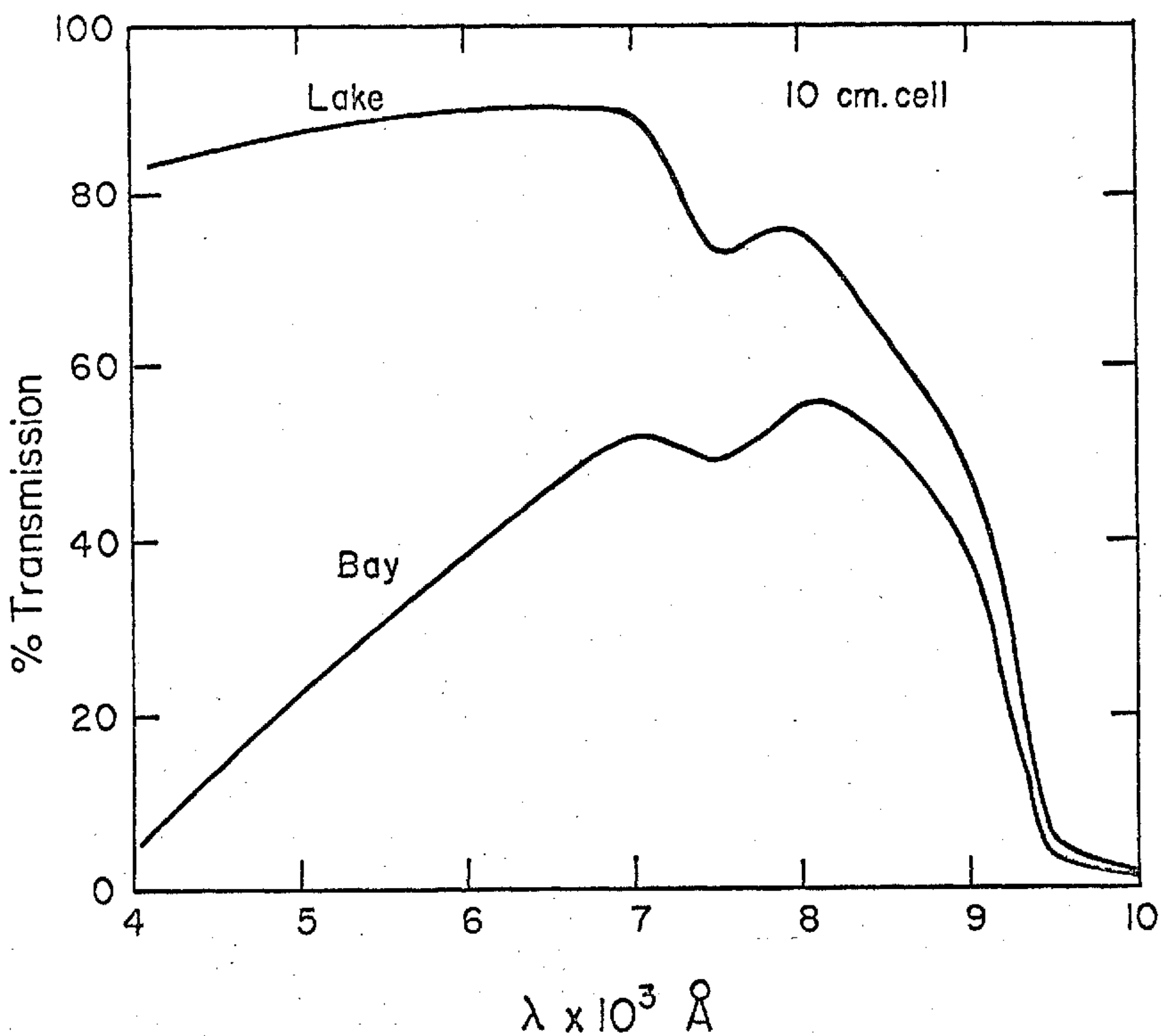
Fig. 3



HARBOR & LAKE IMAGE DENSITY LEVEL Vs. LAKE TURBIDITY
ERTS E-1434-5 SEP 30 1973

Fig. 4

Fig. 5



Lake
10 cm. cell
Bay
% Transmission
100
80
60
40
20
0
4
5
6
7
8
9
10
λ x 10³ Å

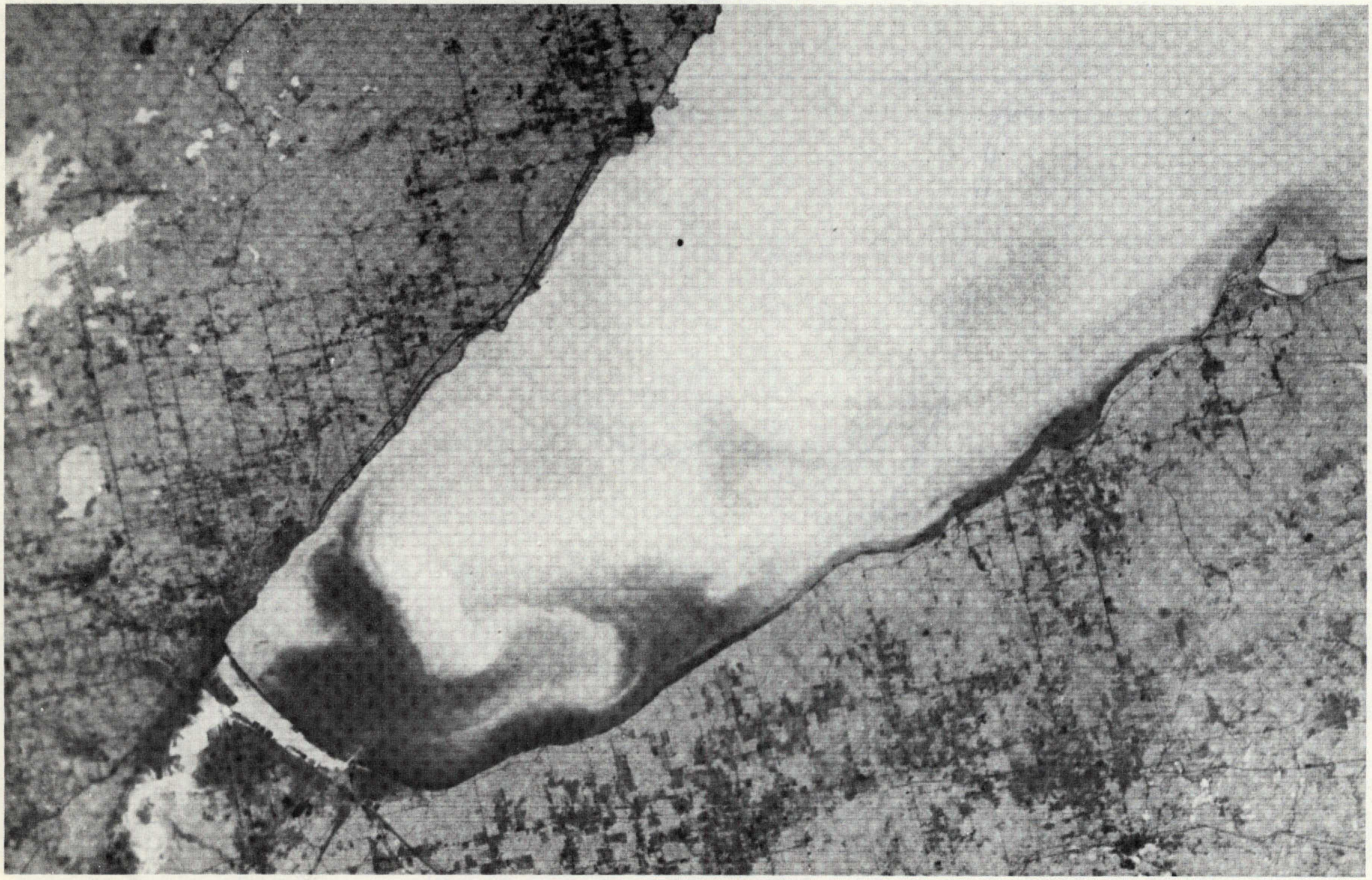
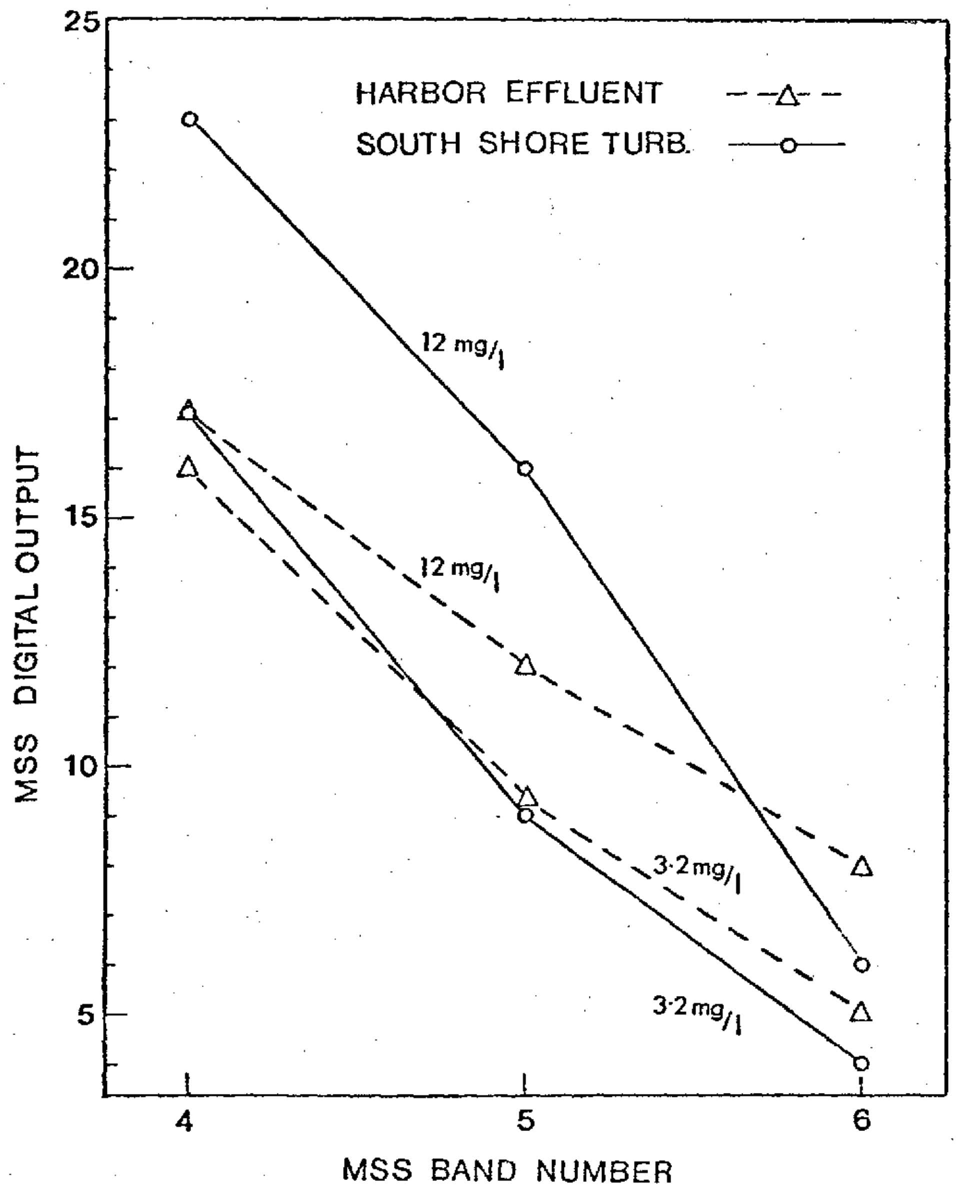


Fig. 7



HARBOR EFFLUENT
SOUTH SHORE TURB.
12 mg/l
12 mg/l
3·2 mg/l
3·2 mg/l
MSS DIGITAL OUTPUT
MSS BAND NUMBER
25
20
15
10
5
4
5
6

Fig. 8

Appendix B

USE OF ERTS IN MEASUREMENTS OF WATER QUALITY IN LAKE SUPERIOR AND THE DULUTH SUPERIOR HARBOR

Peter Bennett and Michael Sydor

Lake Superior Basin Studies Center

University of Minnesota, Duluth

Duluth, Minnesota 55812

ABSTRACT

Correlation of ERTS data and spectrophotometer measurements with measurements of suspended solids for Lake Superior and the Duluth-Superior harbor shows that the suspended solids for surface waters of Lake Superior can be measured from ERTS 70mm bulk data with better than 20% accuracy. The results of the correlation are used in production of a turbidity map for the extreme western arm of the lake. Limitations on the accuracy of the remote sensing measurements establish the lower threshold of detectability of suspended load at 8 mg/ℓ, for the Superior Bay. These limitations are due to atmospheric scattering, water surface conditions and light absorption. Variability of atmospheric conditions demands a calibration point for each image. The effects of the absorption cause the volume reflectance for the Superior Bay to be four times lower than the volume reflectance for Lake Superior water bearing equivalent suspended load.

INTRODUCTION

The extreme western arm of Lake Superior shows pronounced turbidity patterns due to red clay erosion, and effluents from the St. Louis and the Nemadji Rivers. The Duluth Superior area offers excellent conditions for remote sensing studies of natural and man-made problems pertaining to water quality.

The use of remote sensing in studies of sediment transport and effluent tracing requires the correlation of the MSS data with ground measurements. The problem is rather complex. For example, from examining the ERTS data for the Duluth area, the Duluth Superior harbor appears less turbid on the MSS 5 image than Lake Superior, while the ground measurements indicate the converse. To investigate the sediment transport in the Superior Bay and Lake Superior due to natural effects such as run-off and beach erosion, and man-made effects such as shipping and dredging, it is evident from the size of the area involved and the dynamic nature of the problem, that the use of remote sensing is essential, since it allows one to extend measurements taken at a few carefully chosen sites to other areas of the lake. The Duluth Superior region has two distinct areas of interest: the harbor area, characterized by water with high light absorption and total solids, and the lake area, where the water at times carries a large suspended load but has relatively small amounts of dissolved material. The intensity of scattered light from the two areas differs greatly, thus several questions need to be answered before remote sensing data can be effectively used for quantitative analysis. It is necessary to determine the depth of origin of the observed scattered light, its dependence on sediment concentration, its spectral distribution and its dependence on water surface variations and atmospheric conditions.

For this purpose, measurements of suspended solids, turbidity, dissolved solids, and transmission coefficient were correlated with measurements from an on-board spectrophotometer and the MSS data from ERTS, all taken on the same day.

EXPERIMENTAL METHOD

The portable spectrophotometer was made from a high intensity 1/4 meter Bausch and Lomb monochromator operating with 20 Å band pass coupled with a S-13 response photomultiplier as shown in Fig. 1. A photodiode, viewing a white reflector, was used to continuously monitor the relative intensity of incident light. The photometer scanned alternately the water and a K-C reflector in the 3500Å - 7000 Å range. Water samples taken at each station were analyzed for suspended solids and turbidity. The transmission coefficient was measured using a Beckman DK-2A Spectrophotometer. The locations of the stations were determined from analysis of ERTS data for the area. The satellite images indicated that turbid regions of the lake are characteristically present along the south shore of Lake Superior and along the Minnesota Point.[1] The locations marked in Figure 2 are the sites where the on-board spectrophotometer data was taken on September 30, 1973. Water quality and water velocity measurements were made at fifteen additional sites. The correlation of the suspended solids with ERTS data for MSS 5 and the spectrophotometer data for λ = 6000 Å is shown in Fig. 3.

DISCUSSION

The volume reflectivity of pure deep water is quite low, and could be taken nominally as zero. For a clean lake, however, with illumination from the sun and the sky, a certain contribution to the MSS signal comes from the reflection of light by the water surface. This can be seen from work done by Scherz and Van Domelen.[2] The size of the contribution to the MSS signal due to specular reflection can be estimated from Fig. 3 by extrapolation of the spectrophotometer line to zero suspended solids. The error bars on the spectrophotometer data indicate the variability of the observed signal with different water surface conditions. A certain portion of the MSS signal is also due to light scattered from the atmosphere, or path luminence. The size of this contribution is difficult to assess, and would certainly depend on cloud conditions, haze, etc. We concern ourselves here with data taken primarily on clear days, noting, however, that even on those days which appear clear, a range in the MSS signal exists due to the atmospheric scattering. The variability of path luminence, however, seems to simply displace the line in Fig. 3 vertically, leaving its slope the same.[3] Thus a calibration measurement would establish the location of the curve for the lake area for any given day. Aside from these relatively constant contributions to the signal, we can derive a reasonably accurate dependence of the scattered light intensity on the suspended solids. In fact, the measurements of suspended solids are probably responsible for most of the scattering of the experimental points. A straight line is drawn for the points in Fig. 3, though the depth of water observed over this range of suspended solids is not constant. Using this curve and density slicing of ERTS image, we are able to produce, for the areas away from the St. Louis River, a water quality map giving the distribution of the suspended loads near the surface for Lake Superior, as shown in Fig. 4.

ERTS band 5 is used in production of this map, since this band displays the largest range of signal intensity for the lake water. This is not the case for water in the harbor area, which on the MSS 5 image for September 30, appears quite clean. To explain this low signal, we consider the transparency of water, as shown in Fig. 5. It is noticed that the bay water has better relative transmission in the ERTS band 6 region, while the lake water shows the best response in band 5. Note, however, that the transparency of the bay water for the entire spectral region is low. It is related to the dissolved solids content as shown in Fig. 6. The Superior Bay water characteristically has a high dissolved solids content (120-200 mg/ℓ) (lake water has values a factor of our lower). Its suspended solids content varies from 5 mg/ℓ to 20 mg/ℓ, except for unusual times,[1] and averages about 10 mg/ℓ. The intensity of light which penetrates to a certain depth, scatters and reemerges, depends on the absorption of the medium. Thus, light transmission in effect determines the depth of water observed by the remote sensing instrument, so only a shallow layer of suspended sediment can be observed on the bay. This can be illustrated using Fig. 7. The upper solid line shows the depth of the origin of the back-scattered light as a function of the secchi transparency for lake water[4] containing 10 mg/ℓ suspended solids, a value characteristic of the bay. The dashed line indicates the total signal observed for the lake. For the same illumination, the bay water would show a relatively lower total signal because of the absorption. Using the relation between the scattered light intensity from the bay I_B, the scattered light from the lake I_L, and the absorption coefficient μ for the bay water, we arrive at the total signal which we would expect to receive for bay water containing 10 mg/ℓ suspended solids.

$$I_B = \int_0^\infty I_B(x)\,dx = \int_0^\infty I_L(x)\,e^{-2\mu x}\,dx$$

The result is shown by the dotted line in Fig. 7. It indicates that the total scattered light received for the bay would be about 25% of the total signal that would be observed from lake water with an equivalent suspended load.

This agrees well with the values for lake and bay obtained from ERTS MSS 5 data for September 30, 1973 (Fig. 3). The lower solid line in Fig. 7 shows the corresponding reduction in secchi transparency for the bay water due to absorption.

Further examination of the results in Fig. 3 for the bay water indicates that, if a curve could be drawn through the few available experimental points, the signal observed for the bay would approach the lake value for a high suspended load. This is expected to occur when the mean-free scattering length becomes smaller than the absorption length for the bay water, as is often the case in the Allouez Bay. Both curves would flatten out for very high suspended solids, in which case the signal intensity is limited by conditions on multiple scattering.

Figure 3 shows that the lower threshold of detectability of suspended solids on the bay (using MSS 5 70mm bulk images) is 8 mg/ℓ, since for smaller values, the expected signal is less than the error values discussed earlier. The turbidities on the bay well exceed 8 mg/ℓ for conditions of run-off, dredging, and possibly concentrated ship traffic.[1] It is, however, difficult to assess the latter because of insufficient data. The above arguments tacitly assume a uniform distribution of particles with depth for the purpose of illustration of effects due to absorption. This often is not the case, particularly in dredging plumes and river plumes. A change in the concentration of particles with depth, due to variability in settling rate, can well produce significant changes in the observed signal, as shown by the band like structure of the St. Louis River plume off the Superior entry (Fig. 8). This effect is due to the mixing processes of the water in which the edge of the plume appears as rolling billows of turbid water propagating into the lake. Such patterns are often observed at the entries to the harbor.

REFERENCES

1. Sydor, M., Yearly Report to NASA Contract NGL 24-005-263, March 1973.

2. Sherz, J. P. and Van Domelen, J. F., EPA Second Environmental Quality Sensor's Conference, Las Vegas, October 1973.

3. Sherz, J. P., Sydor, M., and Van Domelen, J. F., Third ERTS Symposium, Washington D.C., December 1973.

4. Sherz, J. P., private communication.

FIGURE CAPTIONS

Fig. 1: Schematic of apparatus.

Fig. 2: Location of spectrophotometer stations.

Fig. 3: Data for suspended solids vs. reflectance.

Fig. 4: Turbidity map for Lake Superior.

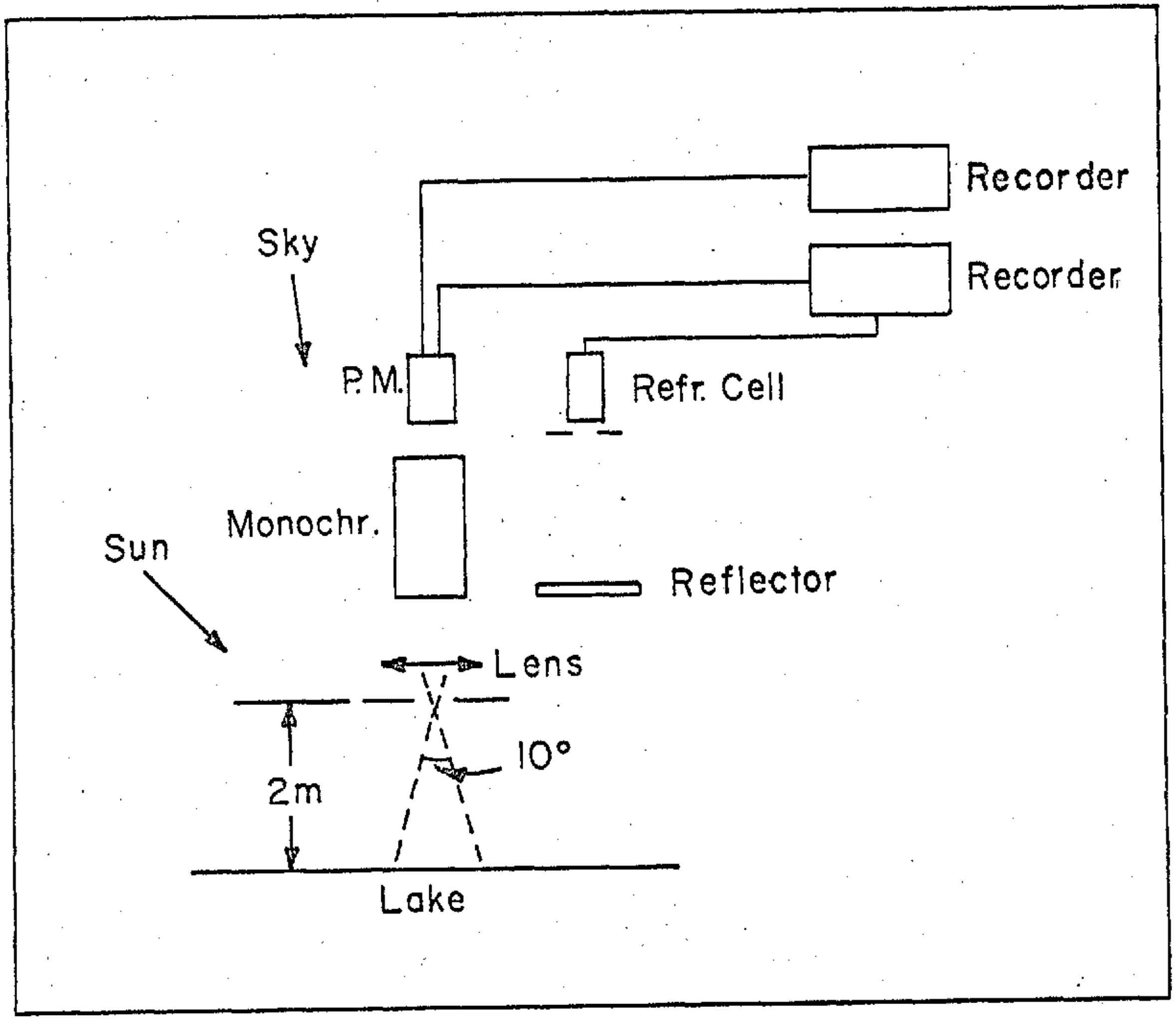
Fig. 4.1: ERTS Image for Sept. 30, 1973 (MSS 5).

Fig. 5: Dissolved solids vs. % transmission for Superior Bay samples.

Fig. 6: Typical water transparency curves for Lake and Bay.

Fig. 7: Scattered light intensity vs. depth of origin.

Fig. 8: Aerial photo of the Superior Entry.



Recorder
Sky
Recorder
P. M.
Refr. Cell
Monochr.
Sun
Reflector
Lens
10°
2m
Lake

Fig. 1

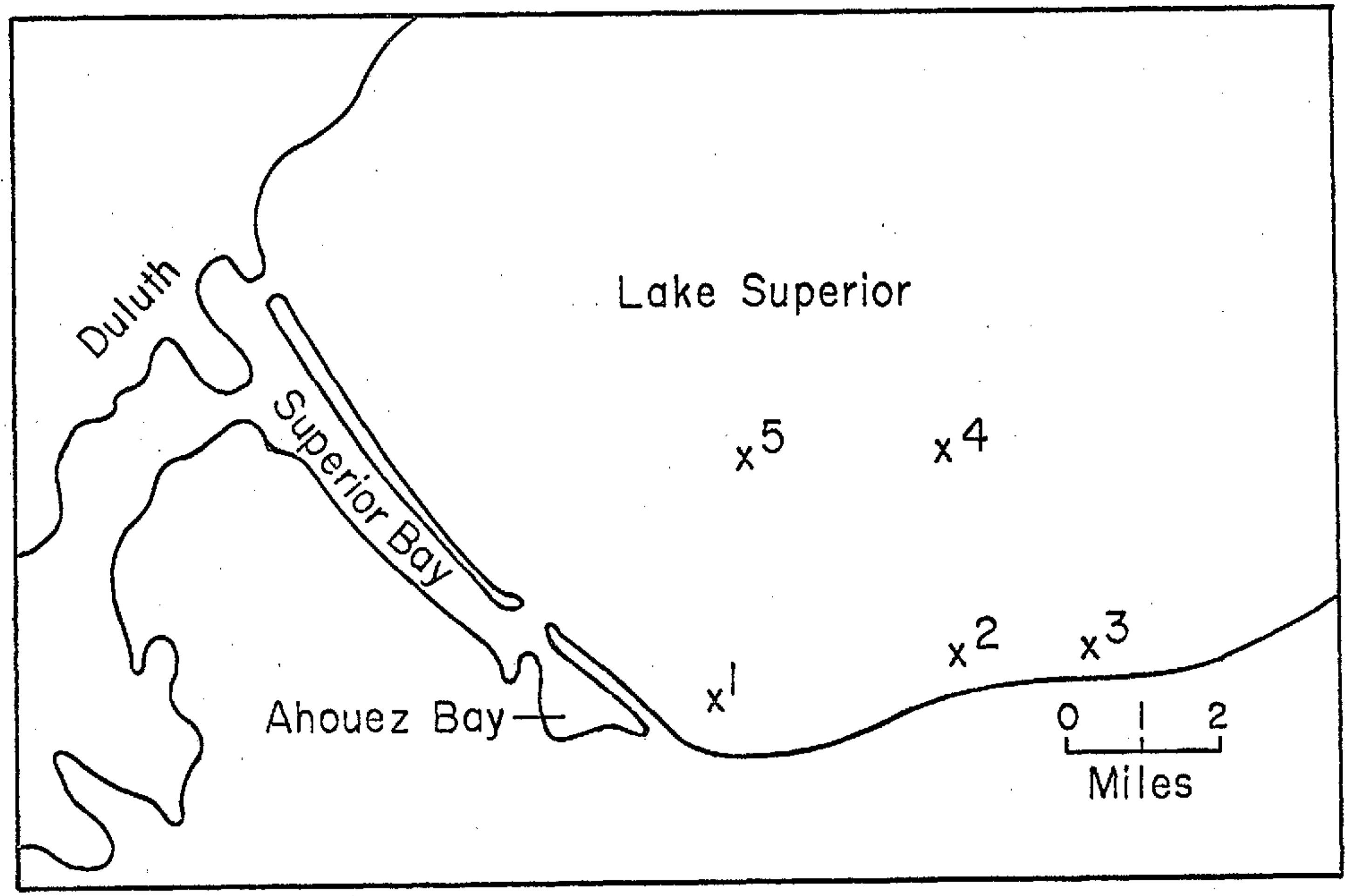

Lake Superior
Duluth
Superior Bay
Ahouez Bay
x 5
x 4
x 1
x 2
x 3
0 1 2
Miles

Fig. 2

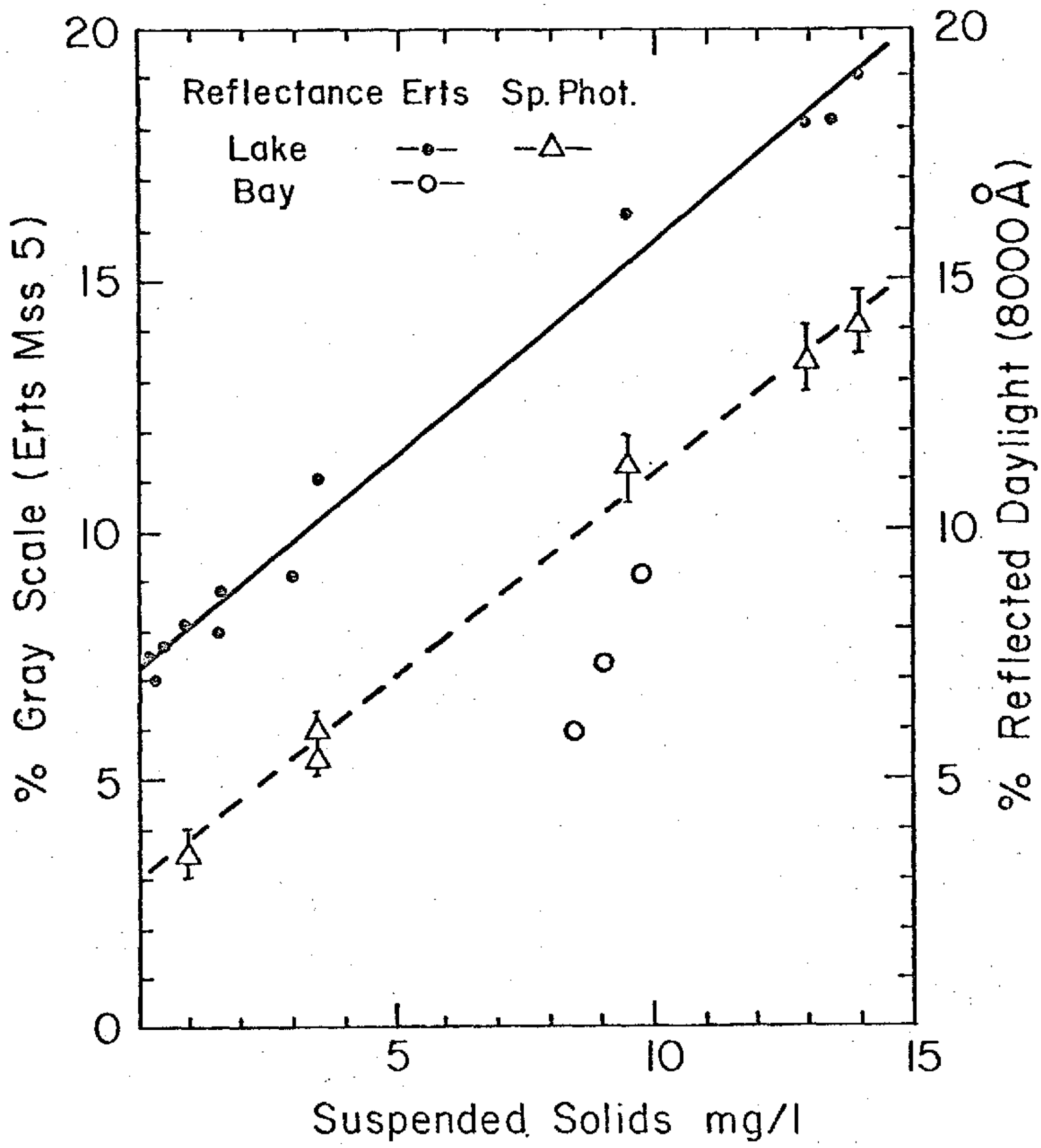

20
15
10
5
0
5
10
15
20
15
10
5
Reflectance Erts Sp. Phot.
Lake
Bay
% Gray Scale (Erts Mss 5)
% Reflected Daylight (8000 Å)
Suspended Solids mg/l

Fig. 3

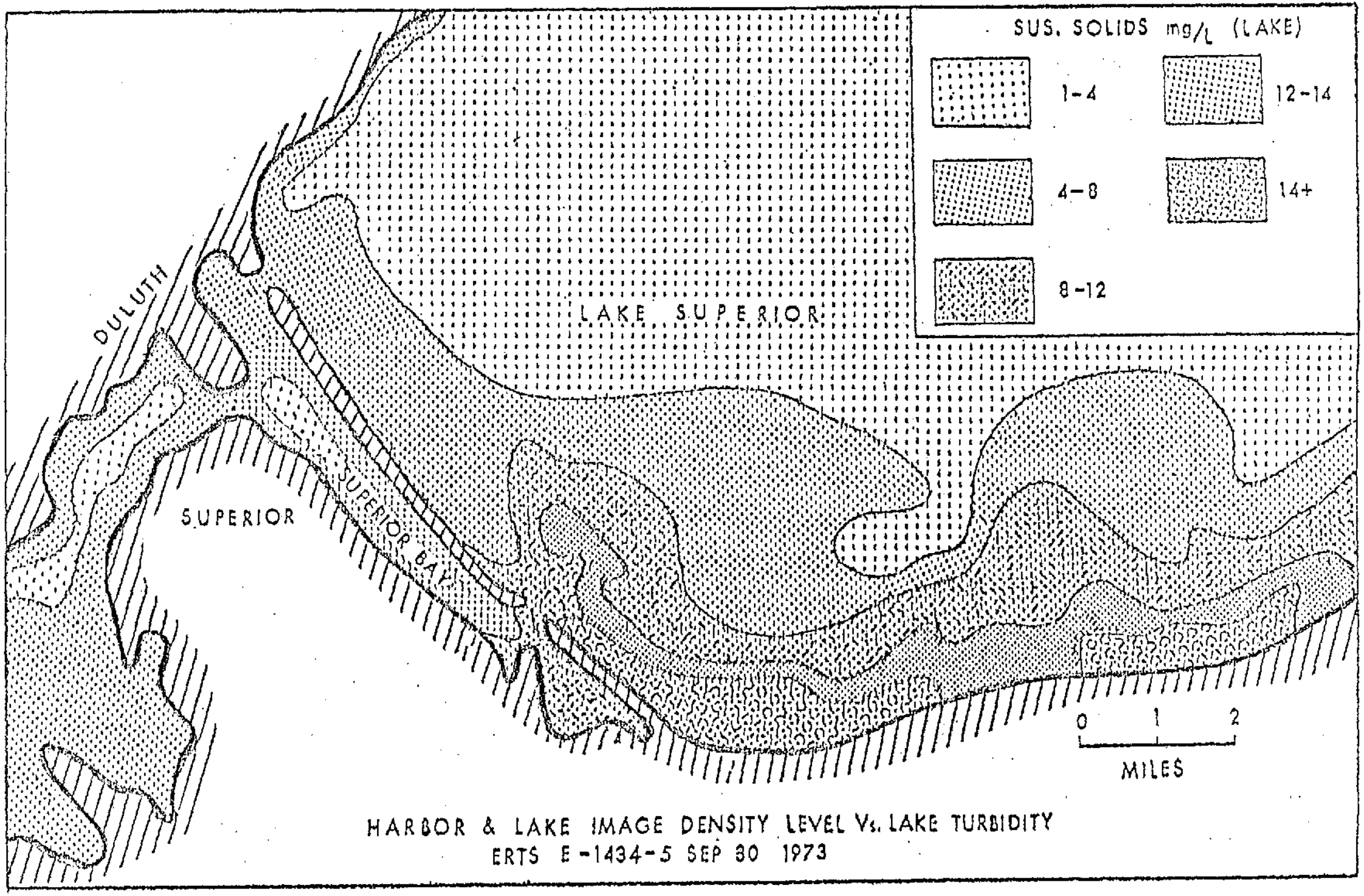

SUS. SOLIDS mg/L (LAKE)
1-4
12-14
4-8
14+
8-12
LAKE SUPERIOR
DULUTH
SUPERIOR
SUPERIOR BAY
0 1 2
MILES
HARBOR & LAKE IMAGE DENSITY LEVEL Vs. LAKE TURBIDITY
ERTS E-1434-5 SEP 30 1973

Fig. 4

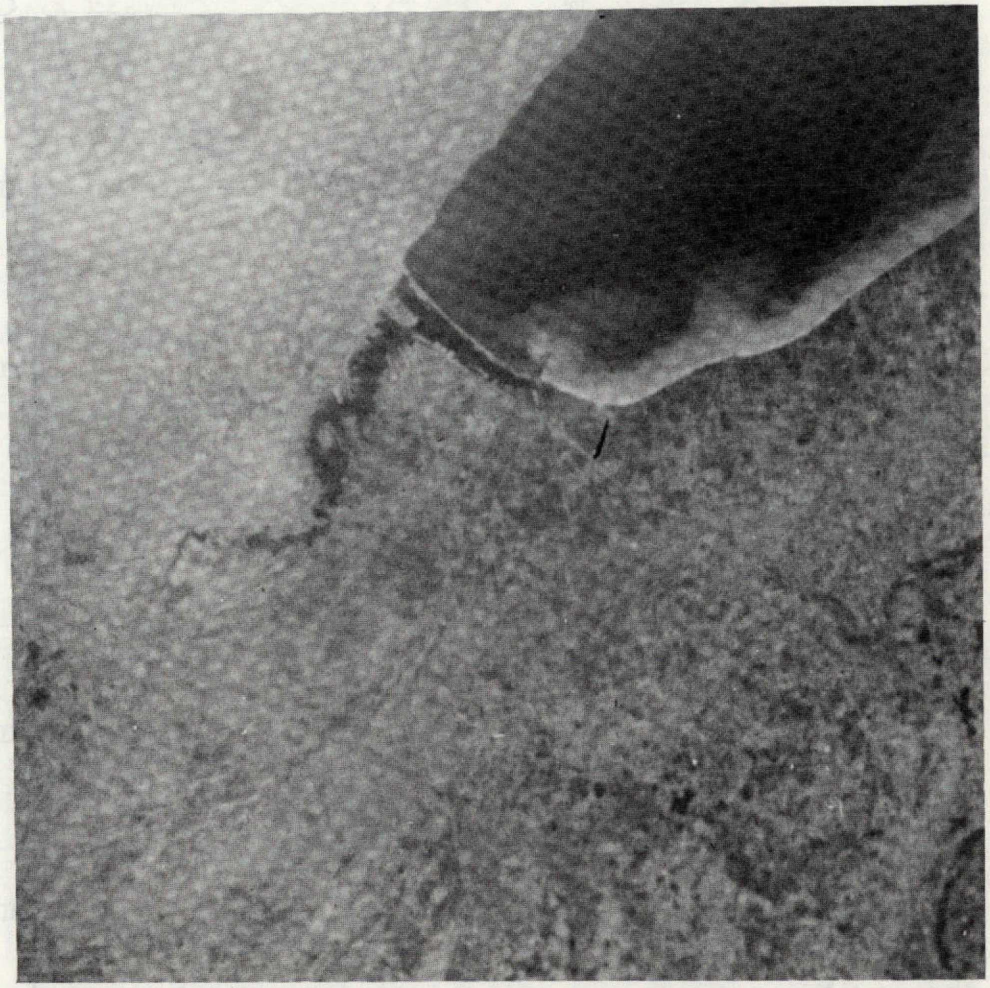


Fig. 4.1

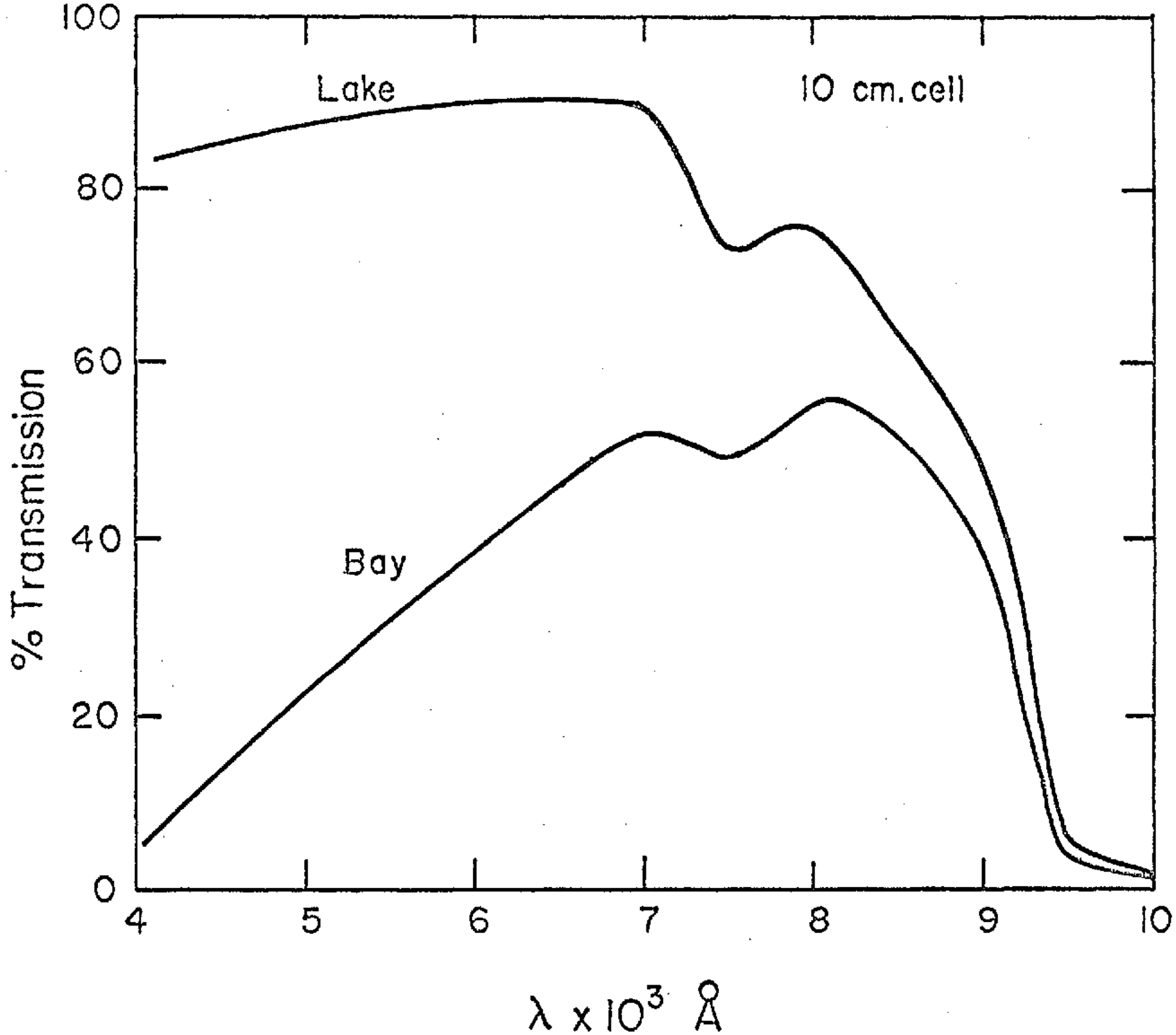

Lake
10 cm. cell
Bay
% Transmission
0
20
40
60
80
100
4
5
6
7
8
9
10
λ x 10³ Å

Fig. 5

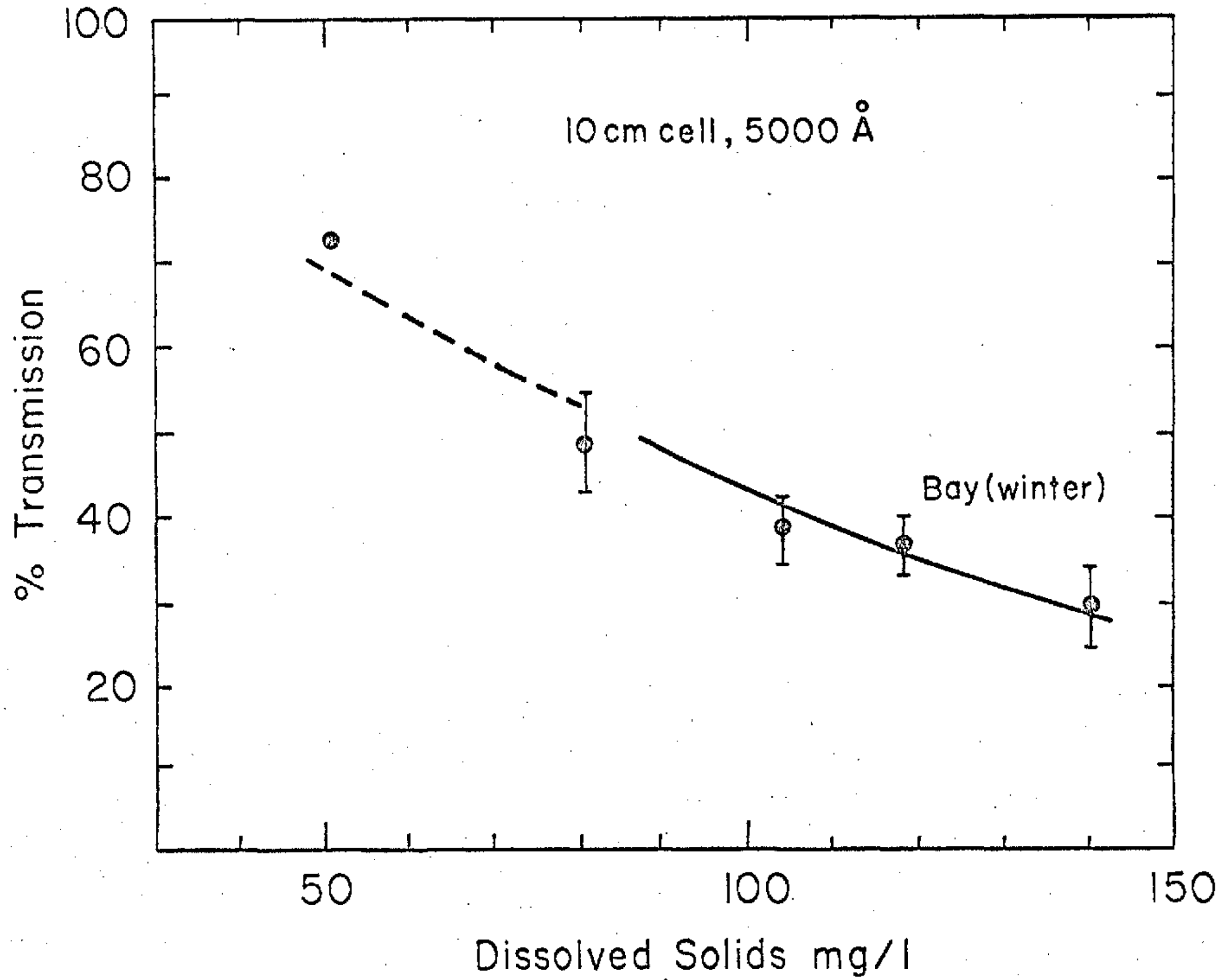

100
80
60
40
20
% Transmission
10 cm cell, 5000 Å
Bay (winter)
50
100
150
Dissolved Solids mg/l

Fig. 6

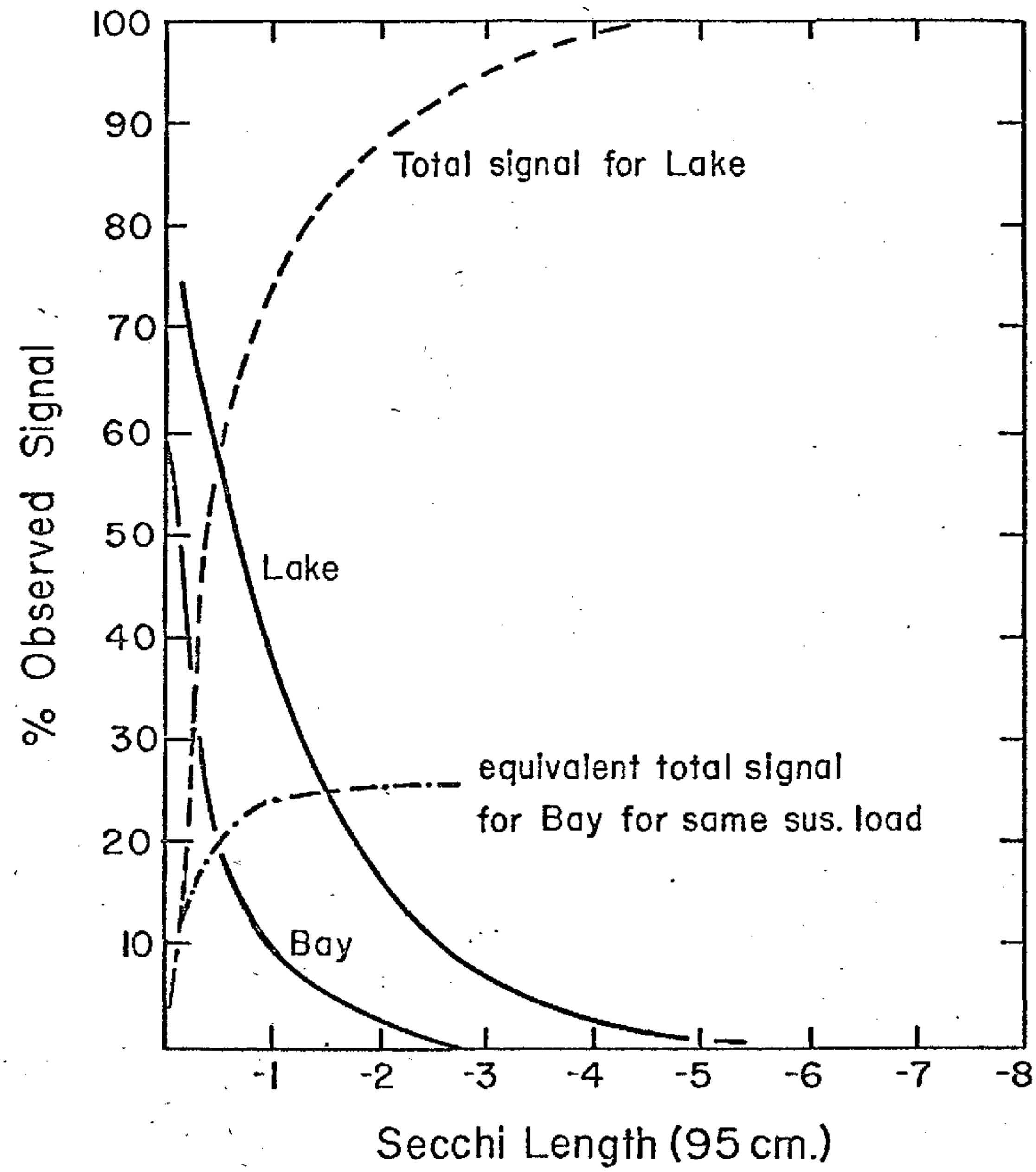

100
90
80
70
60
50
40
30
20
10
% Observed Signal
Total signal for Lake
Lake
equivalent total signal
for Bay for same sus. load
Bay
-1
-2
-3
-4
-5
-6
-7
-8
Secchi Length (95 cm.)

Fig. 7

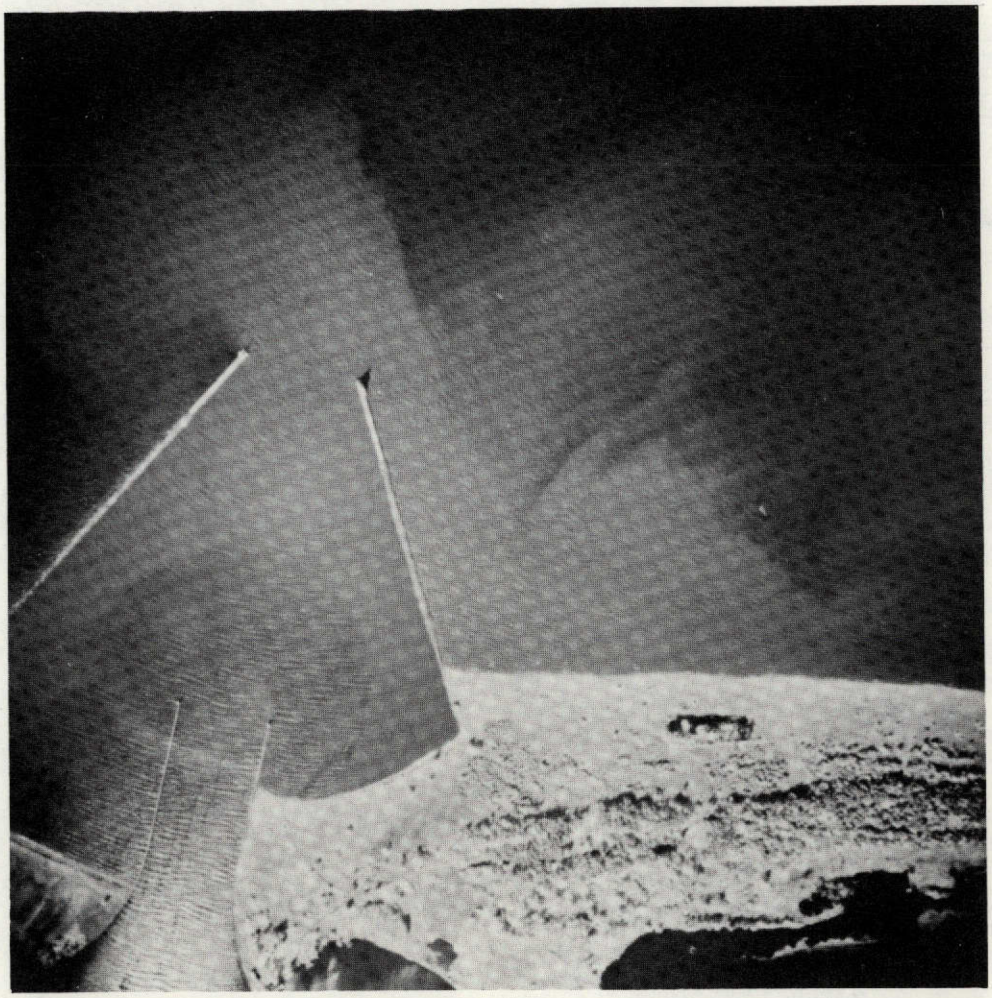


Fig. 8

Appendix C

Abstract of Presentation

Seventeenth Annual Great Lakes Research Conference

Hamilton, Ontario

(August 12-15, 1974)

DETERMINATION OF LAKE SUPERIOR CURRENTS FROM
TURBIDITY PATTERNS OBSERVED FROM ERTS

W. Maanum and M. Sydor

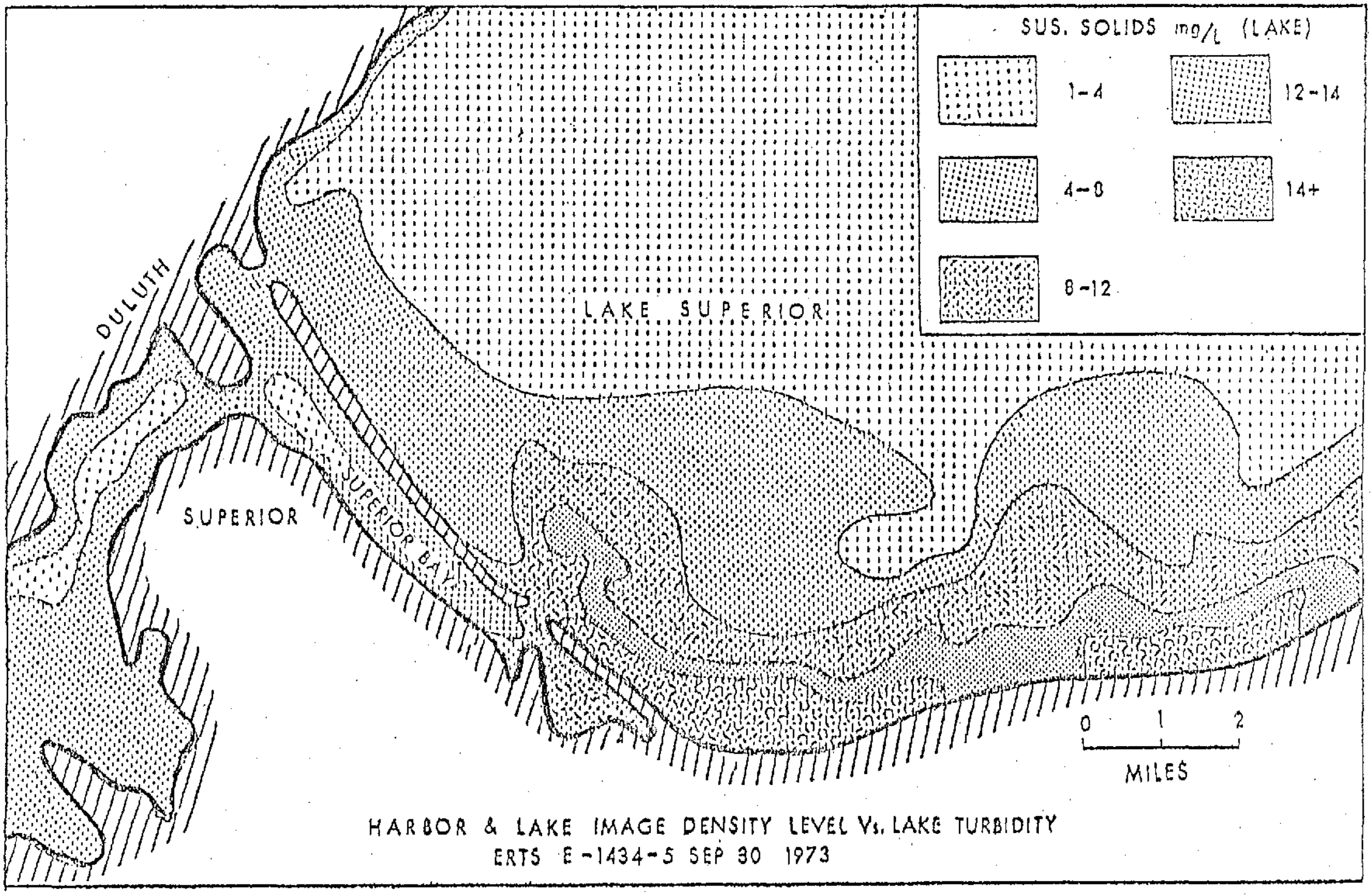
Lake Superior Basin Studies Center
University of Minnesota, Duluth
Duluth, Minnesota 55812

Comparison of ERTS images with surface water current measurements in the extreme Western arm of Lake Superior shows that the turbidity patterns seen by ERTS can be used in extending data taken at fixed stations to other areas of the lake, and in particular, can be used to determine the surface layer circulation pattern of the extreme western arm of the lake. The data shows two characteristic current patterns depending on the wind history. The current pattern for the summer and early fall shows an eddy confined to the extreme western end of the lake. The eddy is complex and much smaller than the general circulation in the western arm investigated by T. Olson, T. Odlaug, and O. Ruschmeyer.

The currents are discussed in terms of sediment distribution obtained from ERTS data, current and temperature measurements and the bottom features of the lake. The presence of several sources of turbidity, as well as the peculiarities of the circulation pattern are generally responsible for

prolonged periods of deterioration of the water quality in the area.

The dynamic nature of the current pattern is shown by comparison of measurements and ERTS data for consecutive days. The motion of water below the thermocline is found to be distinct from the top layer currents. The shape of the bottom of the lake presents a trough-like geometry along the northeastern shore of the lake. For the times when the thermocline is at depths below 100 feet, the bottom currents near Duluth are essentially confined to the trough. Under certain wind conditions, these bottom currents are believed to be responsible for cold water upwelling along the Duluth shore. At these times one finds very clear water above the trough, characterized by secchi transparencies of up to 30 feet, whereas the remainder of the area has relatively turbid water.



HARBOR & LAKE IMAGE DENSITY LEVEL Vs. LAKE TURBIDITY
ERTS E-1434-5 SEP 30 1973

Fig. 1

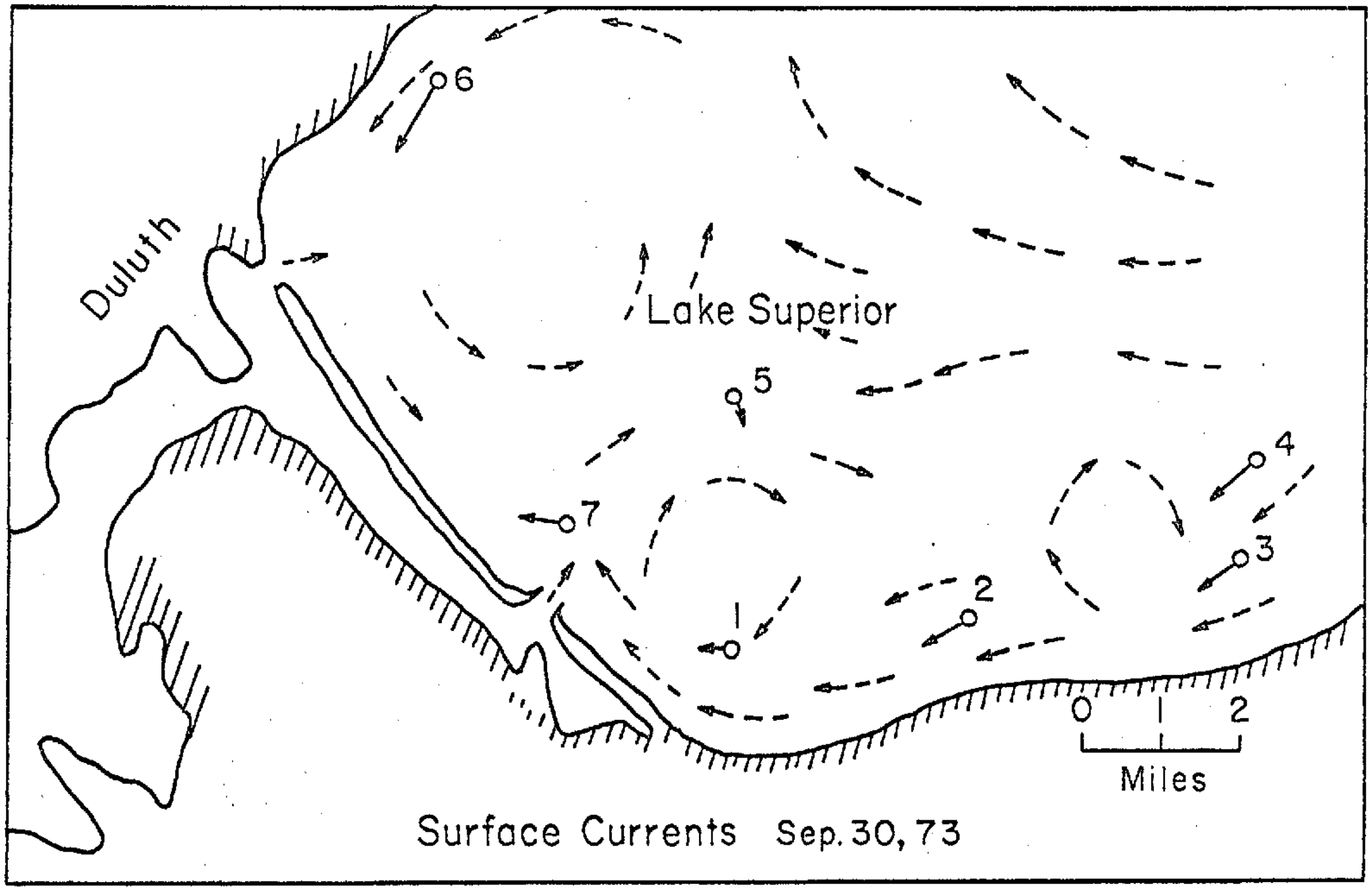

Duluth
Lake Superior
6
5
4
3
2
1
7
0 1 2
Miles
Surface Currents Sep. 30, 73

Fig. 2